The TREND

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IN ENGINEERING

at the University of Washington

UNIVERSITY · OF · WASHINGTON
LVX · SIT
1861

In this issue:

- Contributions of Beuschlein to Studies of Wood Utilization
- Production of Wood Coke from Waste Wood
- The Year in Retrospect
- Slip of Structural Steel Bolted Joints
- Abrasion Resistance of Coniferous Wood
- A Basic Amplifier
- Electrolytic Chromium
- Lightweight Concrete Aggregate

October, 1949

VOL. 1, No. 4

SOMETIME in the summer of 1591, Antonia da Ponte completed the Rialto Bridge which today spans the Grand Canal in Venice, and which Ruskin termed "the best building . . . in the Grotesque Renaissance." Nevertheless, the design, when submitted, and its creator were the center of a furious political controversy.

Senator Marc Antonio Barbaro, for example, a commissioner who supported da Ponte's competitor, Scamozzi, had this to say:

"The art of knowledge in all sciences has its foundation in a recognition of causes, because, as Aristotle says, in most things in nature we come to understand the cause of the effect as the true foundation of those things. So from this we may begin with the origin of the structure of the Rialto Bridge, of which we may discuss each part, first of all, the place." After pointing out that the site was marsh land and quoting Vitruvius and other authorities that "the foundation should be set level" and, if the site does not permit this, that "its ascents and risings should be reduced to a level" (da Ponte was the first to use three levels of piles and inclined bed joints in the abutments), he continued:

"Mathematical science states that parallel lines meet at no point, and even as the Holy Scriptures say that all things disconnected and divided among themselves shall become consumed and be resolved into nothing, so shall these do because they have not an equal base and a common center.

"The foundations of the said abutments are not equally founded, since one part is higher than another, and the lower will perhaps support a greater weight, probably enough to produce ruin."

In spite of this dismal prophecy the bridge survived the severe earthquake of July 10, 1591 and the ravages of the following four and a half centuries, a tribute to the genius of seventy-five-year-old Antonio "of the Bridge" (da Ponte).

— Adapted from William Barclay Parsons, *Engineers and Engineering in the Renaissance*, pp. 522-530, quoting from an unpublished manuscript in the San Marco Library, Venice.

THE Engineering Experiment Station of the University of Washington was established in December, 1917, to co-ordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;

(2) to undertake extended research and to publish reports on engineering and scientific problems;

(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

For administrative purposes the work of the Station is organized into nine divisions:

1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgy, Ceramics
9. Physics Standards and Tests

The control of the Station is vested in a Station Board consisting of the President of the University, the Dean of the College of Engineering as chairman, the Director of the Station, and members of the faculty, representative of the administrative divisions. The Board determines the character of the investigations to be undertaken and supervises the work.

The Station offers a substantial number of research fellowships to highly qualified graduate students who work under the direct supervision of the faculty of the various divisions. The results of the investigations are published in the form of bulletins, technical notes, and reports. Reprints of articles by members of the engineering faculty and graduate students published in recognized technical journals are also issued by the Station. Requests for copies of the publications and inquiries for information on engineering and industrial problems should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

October, 1949

The TREND IN ENGINEERING

at the University of Washington

Vol. 1 No. 4

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COVER

Entrance to Daniel Bagley Hall. With the dedication of this building in 1937 to the use of the Department of Chemistry and Chemical Engineering, the curve of engineering research turned sharply upward.

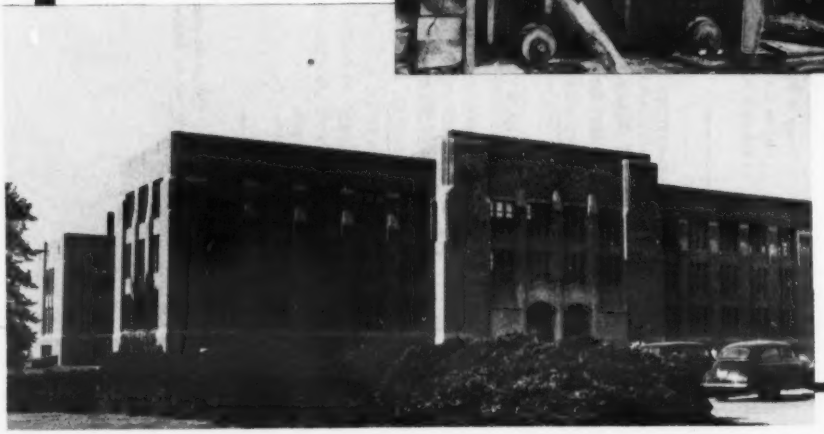
⬅ LEFT

Dr. Henry K. Benson, Professor Emeritus of Chemical Engineering, and from 1907 to 1947 head of the department.

RIGHT ➡

Campus pilot plant for processing wood chips, about 1912.

⬇ BELOW
Bagley Hall



⬆ CENTER

Campus pilot plant for processing wood chips, about 1912. George M. Hunt in foreground.

RIGHT ➡

Dr. Paul C. Cross, Executive Officer of the Department of Chemistry and Chemical Engineering. —Photo courtesy of Seattle *Post-Intelligencer*

Contributions of W. L. Beuschlein in Chemical Engineering Studies of Wood Utilization

Henry K. Benson

Professor Emeritus of Chemical Engineering

THE University of Washington has been interested for many years in the utilization of wood for the manufacture of charcoal and the recovery of other valuable products from waste wood. It is a cheerful task to review in these few pages some of the work undertaken in the past and to recount the important role of the late Warren L. Beuschlein in the development of a new process of wood distillation, that promises much toward meeting the carbon requirements in the region.

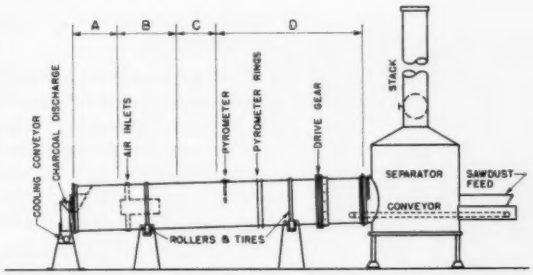
One of the earliest pilot-plant studies in wood distillation was the cooperative program of the Forest Products Laboratory, Madison, Wisconsin, and the University of Washington in 1912-13. A special retort was designed by Marc Darrin who also had charge of the layout and construction of the pilot plant and was the analyst during its operation.[1]

The pilot plant was in charge of George M. Hunt, now Director of the Forest Products Laboratory at Madison, Wisconsin. Some 26 runs on mill waste from four representative lumber-producing sections, viz., Grays Harbor, Hoods Canal, Skagit Company and Lake Washington were made. Runs were made also on several carloads of stumps from Whatcom, Stevens and King Counties, and in commercial plants at Anacortes, and Linnton, Oregon.

The results of these experiments indicated lower yields than those obtained from southern pine and Norway pine. Because of this factor and the difficulty of finding a ready market for charcoal on the Pacific Coast, wood distillation on a commercial scale was considered inadvisable.[2]

In an attempt to develop a method of distillation of greater simplicity and lower costs of installation and operation than hitherto used, Professor Beuschlein designed a semi-commercial rotating kiln for the continuous carbonization of sawdust.[3] A pilot plant, constructed at the sawmill of the Bolcom Canal Lumber Company on Salmon Bay, was in operation for nearly a year producing several carloads of finely divided charcoal, which was used for consumer testing. It was hoped to find a ready market in poultry scratch food but its softness was found detrimental to this purpose.

The Beuschlein rotating kiln is shown in the accompanying diagram. The sawdust is fed at a uniform rate into a slightly inclined horizontal drain and moves toward a zone of partial combustion and distillation. After complete drying the temperature rapidly rises to 275-300° C., and exothermic decomposition occurs. At this point air is admitted for the removal of heavy tars so as to make the charcoal more suitable for poultry use and render it less liable to spontaneous combustion.



Sawdust Carbonizer

A. Reheating Zone
B. Decomposition Zone
C. Heating Zone
D. Drying Zone

Although the market for this kind of charcoal did not warrant a commercial plant in Seattle, it is interesting to know that during the war years, Professor Beuschlein was summoned to Wilmington, Delaware, where he assisted the Hercules Company in preparing working plans for such a plant in Texas where charcoal was made by this method from huge accumulations of sawdust. This charcoal was an activated carbon and was used for water purification in midwestern cities. This process therefore was demonstrated as suitable and practicable for carbon production. It also pointed the way toward a continuous process of carbonization under very simple conditions.

To investigate the production of a low ash coke from waste wood, the Washington State Planning Council in August, 1941, authorized Research Project No. 4 which was organized under the direction of Professor Beuschlein and the writer, with D. W. Meyers, Chemical Engineer, and L. W. Pollock, Research Assistant. Its original object was the production from wood of a coke that might be equivalent in some respects to metallurgical coke for reduction furnaces as well as a coke that approximates petroleum coke for the manufacture of electrodes for electrochemical processes.

The sudden death of Professor Beuschlein, September 15, 1944, occurred before the final report of the project was submitted. The report, however, had been prepared, together with notes and record of the final run, with analyses of the products obtained.

(continued on page 32)

PRODUCTION OF WOOD COKE* FROM WASTE WOOD

Warren L. Beuschlein

Late Professor of Chemical Engineering

W. L. Beuschlein

Introduction

The importance of high quality wood coke to industry in the Pacific Northwest cannot be overemphasized. Ferrous and nonferrous metallurgical industries have not been developed to any great extent in this region partially because of this lack of good quality coke. Much of the coal found in this region is of low grade and is not suitable for coking. On the other hand, the abundance of waste wood available represents a potential source of carbon. The development of an economical process of converting wood waste into a charcoal substitute for metallurgical coke would be an important contribution to the economy of this area.

The heating of wood readily produces, by destructive distillation, a useful form of carbon. This product, charcoal, however, has the disadvantages of low density and poor strength which are of real significance in blast furnace operations.

Chemically, wood charcoal is of high quality. Sulfur and phosphorous, the elements which detract from the value of coke in metallurgical operations, are present only in exceedingly small amounts. A process which would increase the density and strength of wood charcoal would then permit its use in the blast furnace.

In 1941 the Washington State Planning Council authorized a research project for the purpose of investigating the production of low ash coke from waste wood, and provided funds for both research and pilot plant studies. The results of this investigation of a commercially feasible process for the production of a wood coke suitable for industrial use are presented in the following pages.

LABORATORY INVESTIGATIONS

Laboratory investigations were first made to develop a process on a small scale. Douglas fir hogged chips were carbonized in an experimental rotary retort, and the liquid products of the distillation were recovered and concentrated. Yields of charcoal and of wood tar were determined, and from these data was obtained the maximum allowable amount of tar that could be used as binder. Proximate analyses were made to determine the quality of the charcoal produced.

Charcoal briquets were produced by mixing the wood tar binder with the pulverized charcoal, compressing this mixture, and coking the briquets at

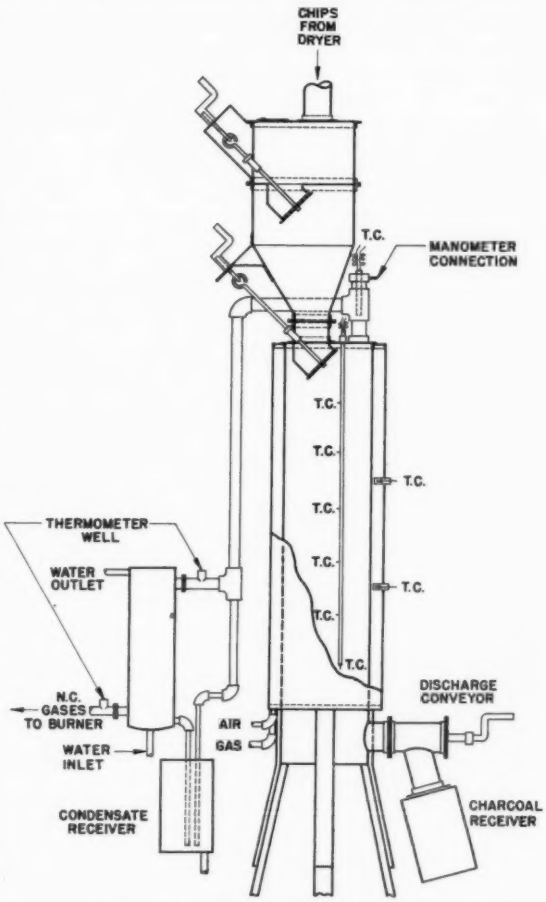


Fig. 1. Cross Section of Retort

*Condensed from the forthcoming Engineering Experiment Station Bulletin No. 117 by R. W. Moulton, Associate Professor of Chemical Engineering, University of Washington.

approximately 650° F. for about thirty minutes. Studies were made to determine the importance of the briquetting variables: the size of the charcoal particles used, the molding pressure, and the amount of binder. It was found that coarse particles when compressed were crushed into a fairly compact mass yielding stronger and denser briquets than when fine charcoal powder was used. An increase in the molding pressure produced an increase in the density and strength of the briquet. Sufficient binder was obtained from the distillation of the wood to produce satisfactory briquets. Proximate analyses of the coked briquets indicated that the volatile matter content of the briquets approximated the volatile matter content of the charcoal from which the briquets were made when the previously mentioned coking conditions were employed.

The briquets considered to be the best were produced employing a molding pressure of 5,000 psi and 28.5 per cent wood tar by weight as binder. These briquets had a density of 0.62 and a crushing strength of approximately 330 psi. The following analysis of these briquets (moisture-free basis) was obtained:

Volatile matter	17.8%
Ash	2.1
Fixed Carbon	80.1
Sulfur	0.03%
Phosphorous	0.005
Heating value	13,450 B.t.u./lb.

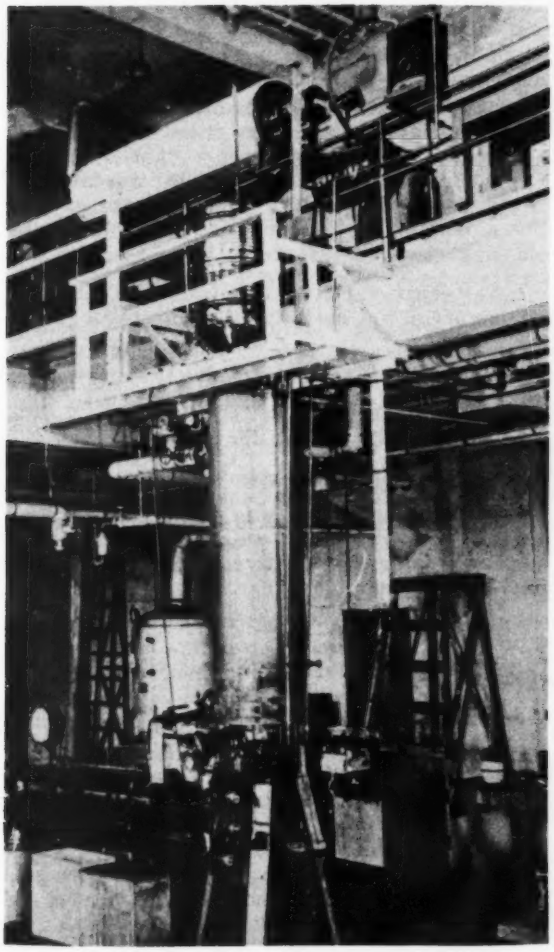


Fig. 2. Complete Charcoal Pilot Plant

Pilot Plant Investigations

In order to determine the commercial possibilities of this process, erection of a pilot plant was undertaken. After a comprehensive study of the available processes for producing charcoal, the Stafford process was selected as the most promising for this work. The reasons for the choice of this process were the following:

1. The wood available was small wood chips which could be satisfactorily handled in a Stafford retort. The size and type selected were similar to the usual chips used in the soda-pulping process.
2. The by-products of the wood distillation, particularly the tar, was needed for a binder in producing the briquets; all by-products can be recovered from a Stafford retort.
3. The process should be economical so that the product, charcoal briquets, can compete with other industrial carbons; the Stafford retort requires very little if any heat and a small amount of labor.

The charcoal plant, consisting of a rotary, direct-fired, countercurrent dryer and a Stafford retort, was designed and constructed to produce 20 lb. of charcoal per hour. (See Figs. 1 and 2.) The dryer was operated separately to obtain data for the drying of Douglas fir chips in a dryer of this type. The dryer and retort were then operated continuously for 33 hours, the products being charcoal, pyroligneous acid, tars, and gases.

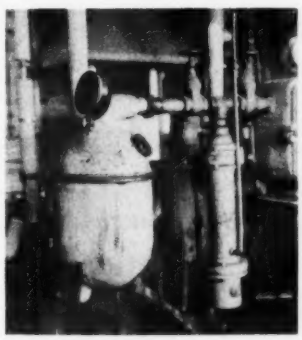


Fig. 3. Steam-Heated Pot Still

The drying data were correlated on the basis of heat transfer and the following equation was obtained from this correlation:

$$h_a = 1.91 + 2.21\ U_{av}^{0.8}$$

where h_a represents the heat transfer coefficient for one pound of wet chips and U_{av}, the average gas velocity through the dryer.

The retort produced charcoal at the rate of 24 lb. per hour. The yields of the various products from the

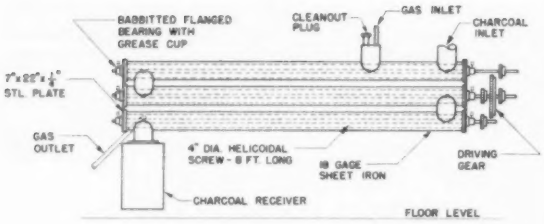


Fig. 4. Diagram of Tar Adsorber

retort are as follows, expressed as per cent of dry wood fed to the retort: charcoal, 38 per cent, condensate, 42 per cent, gases, 20 per cent.

The liquid distillation products were concentrated in a pot still (Fig. 3) and 35 per cent of the total products was recovered for use as binder.

The wood tar was mixed with the charcoal from the retort in a wet-pan mixer (Fig. 4) and it was found that crushing of the charcoal and mixing with the binder was readily accomplished in this apparatus in one operation. It was also found that conditioning of the charcoal previous to mixing it with the tar binder was not necessary. Approximately 1000 lbs. of charcoal-tar mixture was taken to the briqueting plant of the Seattle Gas Company where it was briquetted in a rotary briquetting press. The press and conveyor system at the Seattle Gas Company plant were not particularly suited to the handling of this material, and consequently not as high a yield of briquets was realized as was expected. It is significant that none of the charcoal-tar mixture adhered to the rolls of the press. The briquets which were preserved in their original briquetted form were coked at 650° F. for 1 hour, and were analyzed for volatile combustible matter, ash, and heating value. The analyses of these briquets (moisture-free basis) follow.

Volatile matter	17.6%
Ash	1.1
Fixed carbon	81.3
Heating value	13,700 B.t.u./lb.
Density, apparent	0.65%
Crushing strength (approx.)	400 psi

Conclusions

The most important result of this work is the development on a pilot-plant scale of a continuous process for the manufacture of a high quality wood coke from waste wood. The advantages of a continuous process in which wood chips would be converted to either coke briquets or extruded coke are readily apparent to one familiar with this industry. No binder other than that obtained from the coking of the wood is required. These products can be further processed to yield either activated charcoal or amorphous carbon or graphite electrodes.

A summary of the results of the pilot plant study follows.

1. Strong, hard, and dense charcoal briquets were produced in a pilot plant by the following process:

   a. Drying and heating to 150-200° C. Douglas fir wood chips in a direct-fired, countercurrent, rotary dryer.
   b. Carbonizing these heated chips in a Stafford retort and recovering and concentrating the liquid products of the carbonization.
   c. Simultaneously crushing the charcoal and mixing it with binder consisting solely of concentrated products of the wood distillation in a wet-pan mixer.
   d. Briquetting the charcoal-tar mixture in a commercial rotary briquetting press.
   e. Coking the briquets until the binder was carbonized.

2. The equation for the heat transfer coefficient for one pound wet chips for the pilot plant rotary dryer was

$$h_a = 1.91 + 2.21\ U_{av}^{0.8}$$

where h_a = total heat transfer coefficient (B.t.u./hr., deg. C.) per lb. dry chips and

U_{av} = arithmetic average gas velocity.

3. The Stafford process was suitable for handling Douglas fir chips which were of pulp making size.

4. It was not necessary to condition the charcoal before mixing with the binder.

WARREN LORD BEUSCHLEIN

Warren Lord Beuschlein, a member of the Chemical Engineering faculty from 1922 until his untimely death in 1944, came to the University of Washington with a B.S. in Ch.E. from Carnegie Institute of Technology and two years' experience with the American Nitrogen Company. In addition to his teaching, he continued graduate work at Washington, receiving his M.S. in Ch.E. in 1925 and his professional degree in 1930. In 1937 he was promoted to a full professorship.

Professor Beuschlein was especially interested in wood-pulp problems and most of his publications were connected with that field of research.

At the recent 40th anniversary meeting of the Puget Sound Section of A.C.S., Dr. Henry K. Benson, in reviewing chemical activities of this region paid tribute to Professor Beuschlein for his "clever and original design of a plant for the carbonization . . . of sawdust," and the "energy and directness" with which he carried out that design.

The Year in Retrospect

F. Burt Farquharson
Director of the Engineering Experiment Station

F. B. Farquharson

The past year, which has been the first year of full operation for the Engineering Experiment Station since its postwar expansion, has been a satisfactory one in most respects. The goals set were ambitious, and it is not surprising that all were not fully achieved.

During this period, the total number of research products active at one time or another reached sixty-five, with a total of seventy-eight individual research fellows assigned. The full-time staff in supervision, publications, office, and shop was eighteen. These were assisted by twelve part-time people in different categories.

PUBLICATIONS

Early in this year, an editorial staff was assembled under the direction of Mrs. Isabel Hemenway and active work started on *The Trend in Engineering at the University of Washington*, a quarterly magazine initiated in the interest of better relations with the industries of the Pacific Northwest and distributed to a mailing list of nearly four thousand, including all of the registered engineers in the state of Washington, the various chambers of commerce, the various industries of the region, and the engineering schools and libraries of the country. The magazine is used as a means of publicizing the work of the Station, and the main body of its published material is derived from the experimental work carried on by the many engineering experiment station graduate research fellows at work in the several departments.

This staff is also responsible for the editorial preparation and photo-offset layout of all other publications associated with the Station. Bulletins No. 115 and No. 116, Part I, have been published during the past academic year and Bulletin 117 is in press. Reprints 17 to 25 inclusive have been issued. The Station also cooperated with the Second (1949) Northwest Road Conference as it did with the First (1948) in publishing its *Proceedings*.

PUBLIC RELATIONS

The position of Assistant Director has been filled during the past year by Warren W. Philbrick on a half-time arrangement with the Mechanical Engineering Department. A substantial portion of the Assistant Director's time has been devoted to the problem of public relations and the promotion of a better contact with industry. Under the Station's plan in the case of a specific problem, a preliminary conference or series of conferences between faculty specialists in various fields and the industrial or civic representatives concerned in the problem results in an integrated approach and serves best the interests of the University, the client, and the state. The beneficial effect of these efforts has been evident at many points.

Two examples will serve to illustrate the type of working relations with the public which grew out of intelligent planning of contacts:

1. Project 48, "Preservation of Old Piles," grew out of two round table discussions where representatives of the Fisher Flouring Mills met with a selected group of university experts to consider the important problem of pile infestation. These discussions led to proposals for laboratory study which were facilitated by certain cash grants from Fisher Flouring Mills. Mr. Philbrick has been busy ever since on sundry investigations opened up by this study. A final solution has not yet been achieved, but certain promising leads have opened up.

2. Mr. White of the Fisher Flouring Mills, who had promoted the piling study, came to the Engineering Experiment Station a few months later with a problem of a civic nature. Having been impressed by the outcome of the piling round table discussions, he proposed a similar approach to the vexing problem of landslides in West Seattle. In this case, the City Engineer and Geologist, a drilling expert, certain West Seattle citizens, and civil engineers and geologists from the University, met around the table to explore the possibility of a new approach to the landslide problem.

Their discussion stimulated the organization of Project 66, "Engineering Geology in the Seattle Area." As a result, two research fellows have been roaming the hills of West Seattle ever since, mapping its geology and bringing together information which may lead to a solution of the district's problem. It may also serve as the introduction to a more comprehensive project which the Station has long considered would be of great practical value—that of mapping the geology of the whole Seattle area for the benefit of the building and construction industry.

The recent earthquake which disturbed the area also jolted into existence Project 67, "Earthquake

Investigation," and two geology students under the direction of Dr. Weaver, of the Geology Department, have been active for weeks in the vicinity of the epicenter in the collection of valuable evidence.

In the Fall of 1948, Mr. Philbrick assumed the responsibility for an engineering exhibit in the Labor-Industry Exposition at the Civic Auditorium. This participation was judged to be highly successful. The exhibition was moved out to the Medical School the following Saturday morning, in connection with the entertainment of members of the legislature.

The Assistant Director has also been active with Dr. H. K. Benson, of the Department of Chemical Engineering, in the formation of the Washington Council of Research Laboratories.

RESEARCH ACTIVITIES

During the period embraced by this report, seventy-eight individual graduate research fellows worked on sixty-five separate projects which have been listed and briefly described in the first three issues of *The Trend*. The distribution of these projects and fellows is given by division in Table I.

Special Projects

The two projects listed under the direct supervision of the Engineering Experiment Station are Project Nos. 28 and 29. They are managed by the Director of the Station and are in the nature of general service projects. Project 28, "Electronic Measurements and Controls," is supervised, on a half-time basis, by Andrew B. Jacobsen, of the Electrical Engineering Department. Project 29, "The Electron Microscope," is operated by Oliver Rowe on a full-time basis. The detailed activities of these two projects will be described separately.

Project 28, Electronic Measurements and Controls. The growing importance of electronic instrumentation in all fields of engineering and science has brought a large number of electrical instruments into all departments of engineering. With the exception of electrical engineering, these departments are ill equipped for the intelligent use of this type of equipment. It has also become apparent that such instruments rarely meet the requirements of the problem without some modification, and in many cases existing equipment is quite inadequate.

Project 28, with its own special laboratory, was conceived as a "service must" in the proper use of electronic equipment and as a source of skilled advice in the devising of special-purpose tools. Although set up primarily to serve the Station's needs, this project last year fully demonstrated its utility and value to various outside divisions. In addition to acting in an advisory capacity and as trouble-shooter on numerous projects, it has contributed the following services:

1. Designed and built a decrement computer for Suspension Bridge Investigation (Project No. 14).
2. Designed and built equipment for measuring the height of waves and their pressure impact on bulkheads (Project No. 7).
3. Provided the instrumentation used in displacement and velocity tests on oleo struts (Project No. 52).
4. Designed and constructed a precision voltage regulator for a range of 500 - 1,000 volts for the use of the Chemical Engineering Department in electrophoresis.
5. In answer to a growing demand from all departments, designed a basic amplifier for electronic instrumentation. The first unit is now under demonstration, and plans have been prepared for a limited production.
6. Handled the many continual problems which arise in the modification of surplus equipment.
7. Perfected an arrangement with the Fisheries Research Institute covering the development of certain equipment designed to record the behavior of fish through water-pressure disturbances. It was found necessary to use a tank with sound-absorbing walls and a special microphone to observe the breathing and fin motion of the fish.

TABLE I

Division	No. of Projects	No. of Fellows
Forest Products	7	9
Mineral Engineering	1	1
Aeronautical Engineering	7	9
Chemical Engineering	21	26
Civil Engineering	12	14
Electrical Engineering	6	11
Mechanical Engineering	5	4
Geology	2	3
Physics Standards and Tests	2	1
Engineering Experiment Station	2	-
Total	65	78

Project 29, The Electron Microscope. The electron microscope at the Engineering Experiment Station has been used for investigations during this past year in such widely divergent fields as forestry, microbiology, zoology, metal surfaces, clay studies, and sewage analysis. The recent addition of a high vacuum evaporator to the laboratory equipment has permitted the utilization of the shadow-casting technique, which greatly extends the utility of the instrument. The intelligent use of shadow casting is of especial value in the field of virus study, and certain applications in this direction are already contemplated.

During the past year, the only electron microscope operating in this area has been in the Station Laboratory, so a large assignment of laboratory time has been made outside of the field of engineering.

The following tabulation lists the various activities of the laboratory by department, interested individual, and subject:

Bureau of Mines, U.S.	
Kelly	Analysis of Clays
Boyd and Hilton	McKay Coal
Blair	Wyoming Coal
Chemical Engineering	
Moulton and Pope	Study of Catalysts
Moulton, Mulvaney, and Mukherjee	Study of Activated Charcoal
Lingafelter and Bierlein	Crystal Defraction
Civil Engineering	
Hennes and Bennett	Identification of Clays
Tyler and Maske	Analysis of Sewage and Brewery Waste
Tyler and Orlob	Comminution of Sewage
Tyler, Orlob, and Williams	Chlorination of *E. coli*
Mechanical Engineering	
Mills	Pearlite Structures
Philbrick and Wolfstein	Paint Film by Diffraction
Forestry	
Grondal	Microstructure of Western Hemlock
Philbrick	Wood Flour
Philbrick and Zenczak	Products of Ultrasonic Treatment of Wood
Zenczak	Study of Activated Charcoal
Physics	
Sanderman	Radium in Soils
Microbiology	
Douglas	*Rhodomicrobium*
Douglas and Gardner	*Hyphomicrobium*
Ordal (with Dr. Van Iterson and Dr. Robinow of England)	Caryophanon and myxobacterium
Ordal and Watson	Bering Sea Water
Pennington	Studies of Various Bacteria
Pennington and Schmidt	*B. necrophorus*
Weiser and Myrvick	T. B. Vaccine and Phage
Zoology	
Ray	Iron Bacteria
Whitely	Hamster Sperm
Whitely	Muscle Fibrillae

In addition to the service to various departments listed above, the following educational demonstrations were arranged:

Professor Mills — Mechanical Engineering Class
Dr. Whitely — Advanced Microscopy Class (Zoology)
Dr. Sanderman — Physics Classes (Nursing Majors, Home Economics Majors)
Seattle Foundry Men's Association
Professor Sylvester — Sanitary Engineering Class
National Convention of Civil Engineers
Dr. Henry — Class in Medical Microbiology
Garfield High School Science Teachers
Bremerton Doctor's Aides and Laboratory Technicians
High School Leaders Conference
North Seattle Amateur Radio Club — Lecture
Olympia Brewing Co.

Sponsored Projects

Partially sponsored cooperative research projects were carried on with the following groups:

1. Washington Toll Bridge Authority
2. Public Roads Administration
3. Bonneville Power Administration
4. Fisher Flouring Mills
5. Washington Pollution Control Commission

The Washington Toll Bridge Authority and Public Roads Administration are cooperating with work on suspension bridges being conducted in the Structural Research Laboratory of the Civil Engineering Department.

The Bonneville Power Administration is concerned with the heat-pump project in the Electrical Engineering Department.

Fisher Flouring Mills has an interest in Project No. 48, "Preservation of Old Piles," in the Mechanical Engineering Department.

The Washington Pollution Control Commission is partially sponsoring an investigation of the characteristics and methods of disposal of industrial wastes

produced in the state of Washington, which is being carried on in the Sanitary Engineering Division of the Civil Engineering Department.

Contracts for fully sponsored projects have been signed by the following sponsors:

1. National Advisory Committee for Aeronautics
2. Rushlight Automatic Sprinkler Company of Portland, Oregon

The first project, an investigation of rolling characteristics of swept-back wings on jet-propelled aircraft, is being carried on in the Aeronautical Engineering Department. Work on the second project, "The Ozonation of Sewage," will be done in the Sanitary Engineering Division of the Civil Engineering Department.

The recent legislature appropriated $125,000, which would only become available as matched from other sources, for a study of the gasification of Washington coals. The Engineering Experiment Station was active in the formation of a regional committee, made up of coal and gas experts and representatives of interested groups, which is charged with advisory duties in connection with the study of gasification. The state's appropriation was made to the University, and the Engineering Experiment Station is charged with the responsibility for administering it. When financial arrangements are concluded, the project will be set up jointly in the School of Mineral Engineering, the U.S. Bureau of Mines, and the Department of Chemical Engineering.

On the whole, the past year has shown a promising beginning toward fulfilling the purpose of the Station to further the industrial development of the Northwest, both by the direct results of its research and by training outstanding young engineers in the research techniques which industry requires.

CONDITIONS AFFECTING THE SLIP OF STRUCTURAL STEEL BOLTED JOINTS

Robert A. Hechtman

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R. A. Hechtman

Introduction

Three types of fasteners are commonly used for joining structural steel members: rivets, bolts, and welding. Although there have been many investigations of riveted and welded connections, few tests have been made on bolted joints of the type and size occurring in bridges and buildings.

The structural engineer is interested in both the strength and the slip characteristics of a bolted joint. The need for strength is quite obvious. However, a knowledge of the amount of slip which takes place in a bolted connection is equally important, since slip reduces the rigidity of the joint and increases the deflection of the structure of which the joint is a part.

The strength of bolted connections can be deduced from previous tests of riveted joints and from data on the strength of bolts. The slip characteristics of bolted joints under different loadings can, however, be determined only by test, since the structural bolt does not fill the holes in the plates as completely as a well-driven rivet.

This progress report describes the initial tests of a much larger program whose primary purpose has been an investigation of the manner in which different types of bolted joints slip and of the conditions which affect this slip. These tests are sponsored jointly by the Washington Toll Bridge Authority and the Engineering Experiment Station and carried on in the Structural Research Laboratory of the Department of Civil Engineering. The Type-A bolted joints were tested by R. W. Hager, graduate student in Civil Engineering. The writer is indebted to Professor F. B. Farquharson, Director of the Engineering Experiment Station, for his many suggestions.

TEST SPECIMENS AND METHOD OF TESTING

The double-lap bolted joints tested in this research program were made from plain-carbon structural steel plate meeting Specification No. A 7-42 of the American Society for Testing Materials. The bolts used in the joints were rough forged from high-strength structural steel and heat treated. The threads were machine cut. The yield point of the bolt steel was considerably higher than that of the plate steel. Tensions producing average stresses as high as 60,000 psi in the root of the threads of the bolts caused no perceptible yielding.

The two types of joints tested are shown in Fig. 1 and described in Table I. All bolt holes were drilled and reamed to size. The mill-scale surfaces of the plates were used as the faying surfaces of the joints.

The tension in the bolts provides the normal forces between the plates of a joint and thereby affects the frictional resistance to slip which can be mobilized

TABLE I

DESCRIPTION OF BOLTED TEST SPECIMENS

Test No.	Type	No. of Bolts	Hole Diam. (in.)	Approximate Bolt Tension (lb)
16-18	A	1	1-3/64	18,000
19-21	A	1	1-3/64	24,000
22-24	A	1	1-3/64	30,000
1-3	B	2	1	24,000
7-9	B	2	1-1/64	24,000
4-6	B	2	1-3/64	24,000

to carry the applied loads. In any research program on bolted joints, a comprehensive analysis of the test results requires a knowledge of the actual tensions in the bolts of the test specimens. For this reason, the bolts for the test specimens were individually calibrated under tension loading to determine the relation between the elongation of the bolt and the tension in the bolt before they were placed in the test specimens.

For this calibration, the grip of each bolt was made equal to that occurring in the test specimen. The elongation of the bolts was measured with a sensitive bolt calipers. When the bolts were placed in the test specimens and tightened, the elongation which occurred during tightening was compared with the calibration data to obtain the bolt tension.

All the bolted joint specimens were loaded in tension only. The smaller Type-A specimens were held in the wedge grips of a 300,000-lb capacity hydraulic testing machine. The larger Type-B specimens were bolted to loading heads, which were pin connected to the clevises of a 2,400,000-lb capacity hydraulic testing machine.

The primary purpose of these tests of bolted joints was to determine the relative movement between the adjacent plates of the joint. The gages for measureing this slip were dial indicators graduated in 0.001 in. and were mounted on the test specimen at the points shown on Fig. 1, with specially made brackets. With these gages, the movement of both edges of each lap plate relative to the butt plate was found. The average of the values of the slip at the four edges of the lap plates was plotted together with the average shearing stress on the bolts of the joint to give a load-slip curve.

RESULTS OF TESTS

The research program on bolted structural joints began with an investigation of the effects of two factors upon the slip of the joints: (1) bolt tension, and (2) clearance in the bolt holes. The results of the tests which will be presented and discussed in the following sections represent the exploratory stages of a larger program now in progress.

Effect of the Bolt Tension upon the Slip of the Joint

An exploratory series of nine tests of Type-A specimens was made to determine the effect of the bolt tension upon the slip of the joint. All these specimens had one 63-64-in. diameter bolt in a 1-3/64-in. drilled hole. Three joints were tested with each of the following bolt tensions: 18,000, 24,000, and

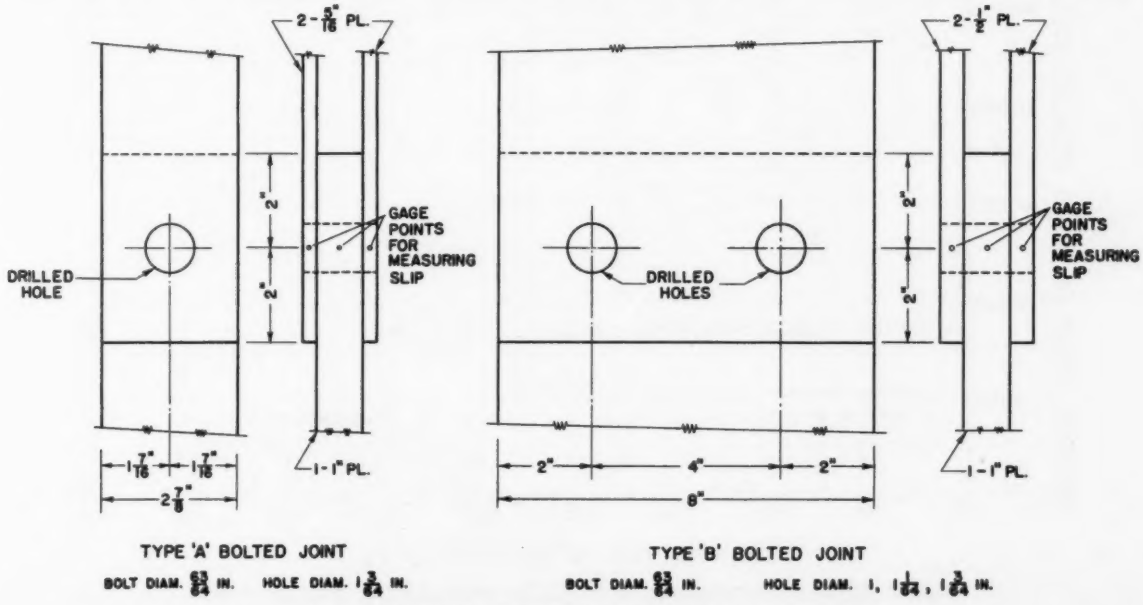

Fig. 1. Different Types of Bolted Double-Lap Joints

30,000 lb. The results of these tests are given in Table II and shown in Figs. 2, 3, and 4.

As load was applied to the bolted joints, a small amount of initial slip occurred. Under further loading, the joint began to slip at a much more rapid rate, often without much increase in load. This point is termed the "shear in bolt at first major slip" in Table II. When the bolt of the joint came into full bearing on the plates, the rate of slip decreased sharply, as shown by the upward turn of the load-slip curves, and further slip took place only as the plates were permanently deformed. The values of the shearing stress at which the first major slip occurred and at which the bolt came into bearing on the plates were selected by inspection from the curves in Figs. 2, 3, and 4 and are given in Table II.

Although the behavior of the single-bolted joints was somewhat erratic, the effect of raising the bolt tension was apparent. An inspection of the values in Table II indicates that the shearing stress on the bolts at which the first major slip occurred increased as the bolt tension was raised.

The shearing stress at which the bolts came into full bearing on the plates was similarly increased for all the joints except Test No. 22. This last test exhibited a behavior under load which was repeated by other bolted joints in this program. After the first major slip, the load sustained by some joints decreased, and further increase of the load on the joint was possible only after an additional amount of slip had taken place. In most of the bolted joints, only a small additional amount of slip was necessary in order to regain a prior load, but the joint in Test No. 22 came into full bearing before it would sustain a larger load.

A probable explanation of this unusual behavior is that the contact between the faying surfaces was sufficiently disturbed as to require a large amount of slip before new contact areas were mobilized into action. An examination after testing of the faying

TABLE II

EFFECT OF BOLT TENSION ON SLIP OF TYPE-A JOINTS

Bolt: 63/64 in. Drilled Hole: 1-3/64 in.

Test No.	Approx. Bolt Tension	Shear in Bolt at 1st Major Slip (psi)	Shear in Bolt at Full Bearing (psi)
16	18,000	7,900	17,400
17	18,000	7,900	13,900
18	18,000	6,100	15,700
19	24,000	12,000	20,500
20	24,000	11,900	22,400
21	24,000	9,700	18,700
22	30,000	16,000	15,700
23	30,000	14,100	27,500
24	30,000	11,900	24,000

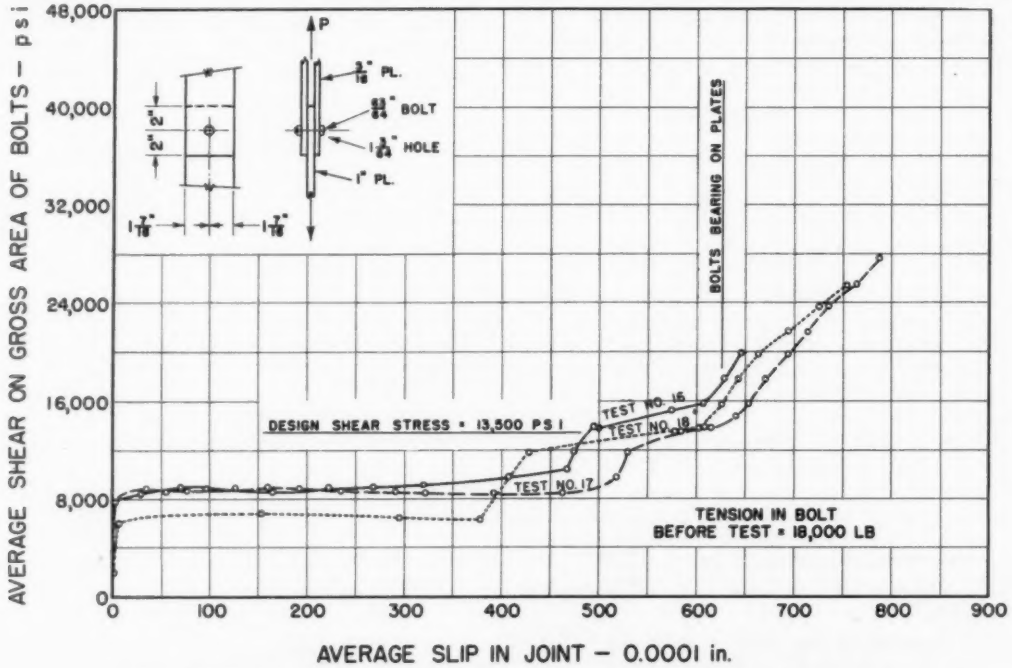

Fig. 2. Effect of Bolt Tension of 18,000 lb on Slip of Double-Lap Joints with One 63/64-in. Diameter Bolt in a 1-3/64-in. Drilled Hole

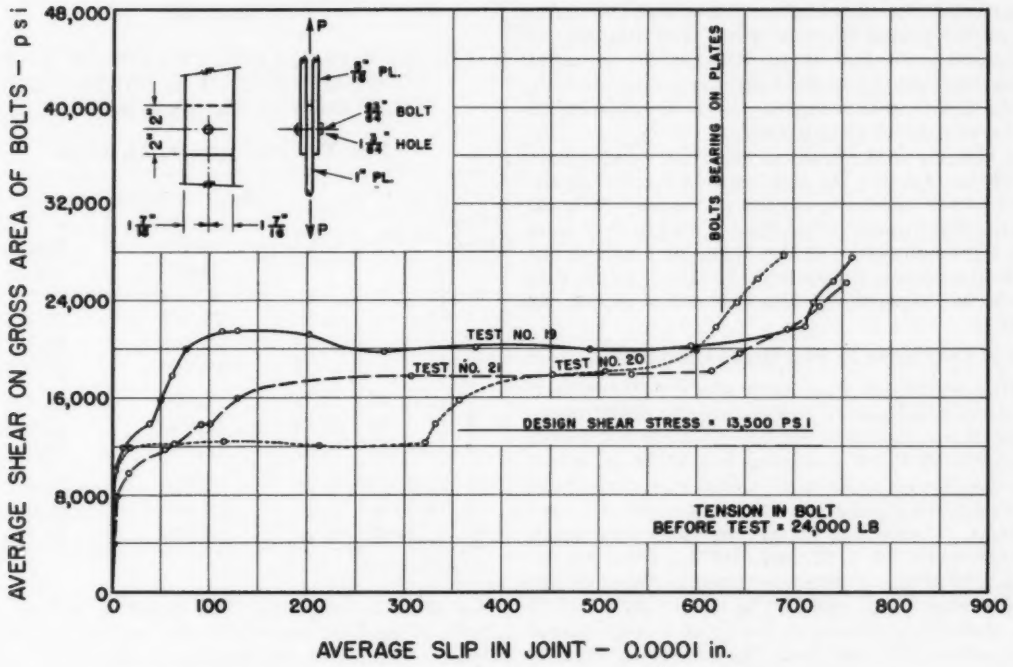

Fig. 3. Effect of Bolt Tension of 24,000 lb on Slip of Double-Lap Joints with One 63/64-in. Diameter Bolt in a 1-3/64-in. Drilled Hole

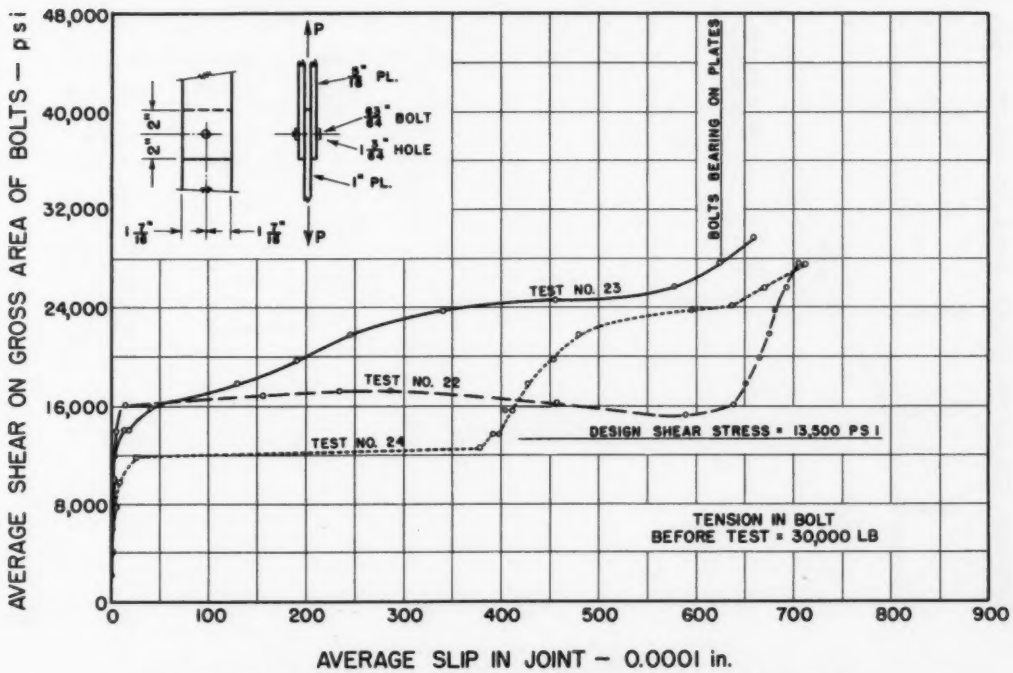

Fig. 4. Effect of Bolt Tension of 30,000 lb on Slip of Double-Lap Joints with One 63/64-in. Diameter Bolt in a 1-3/64-in. Drilled Hole

surfaces of these specimens showed that the plates were galled around the bolt holes. The diameter of this galled area was about equal to the distance across the flats of the head and the nut of the bolt. Outside of this galled region, the mill scale on the plates was only slightly disturbed.

The results of the tests of the single-bolt joints showed that raising the bolt tension caused an increase of the shearing stress necessary to bring about the first major slip. Since a single-bolt joint is not representative of the types of connections used in structures, future tests of larger joints with six bolts are planned with bolt tensions of 24,000 and 30,000 lb.

Effect of Clearance in Bolt Holes upon Slip of Joint

A pilot series of nine tests of Type-B two-bolt specimens was made to investigate the effect of the amount of clearance in the bolt holes in the plates of the joint. All these specimens had 63/64-in. diameter bolts. Three joints were tested with each of the following hole diameters: 1-in., 1-1/64-in., and 1-3/64-in. These hole diameters gave clearances in the holes of 1/64, 1/32, and 1/16 in., respectively. The results of these tests are given in Table III and shown in Figs. 5, 6, and 7. The values in Table III of the shearing stresses on the bolts were obtained by inspection from the load-slip curves of Figs. 5, 6, and 7.

Like the previous tests of the Type-A joint, the tests of the Type-B joints showed a considerable variation in behavior. The shearing stress in the bolts at the first major slip was largest for the 1-in. holes, which had the smallest clearance, 1/64 in. The joints with the 1/16-in. clearance in the holes sustained a little larger shearing stress before the first major slip than the joints with the 1/32-in.

TABLE III

EFFECT OF CLEARANCE IN BOLT HOLES UPON SLIP OF TYPE-B JOINTS WITH TWO 63/64-IN. DIAMETER BOLTS

Bolt Tension: Approx. 24,000 lb

Test No.	Hole Diam. (in.)	Clearance (in.)	Shear in Bolts at 1st Major Slip (psi)	Shear in Bolts at Full Bearing (psi)
1	1	1/64	23,700	28,600
2	1	1/64	15,800	36,800*
3	1	1/64	17,700	27,600
7	1-1/64	1/32	11,000	24,800
8	1-1/64	1/32	11,900	22,000
9	1-1/64	1/32	11,400	10,800
4	1-3/64	1/16	17,700	37,000
5	1-3/64	1/16	13,000	20,000
6	1-3/64	1/16	14,000	23,700

*Approximate.

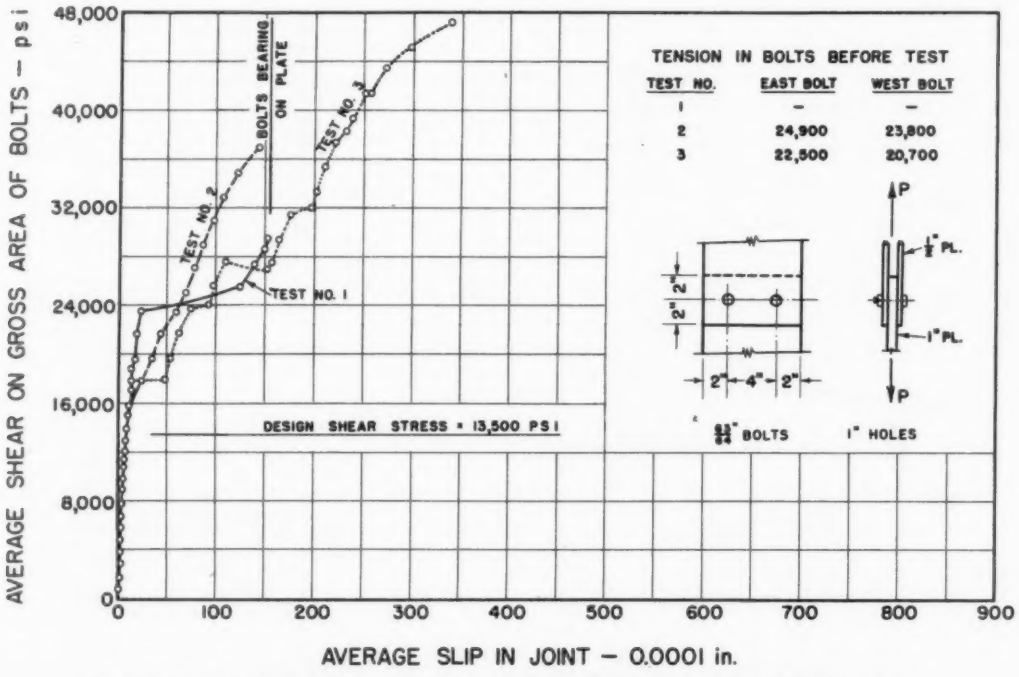

Fig. 5. Effect of Clearance of 1/64 In. in Bolt Holes upon Slip of Double-Lap Joints with Two 63/64-In.-Diameter Bolts in 1-In. Drilled Holes

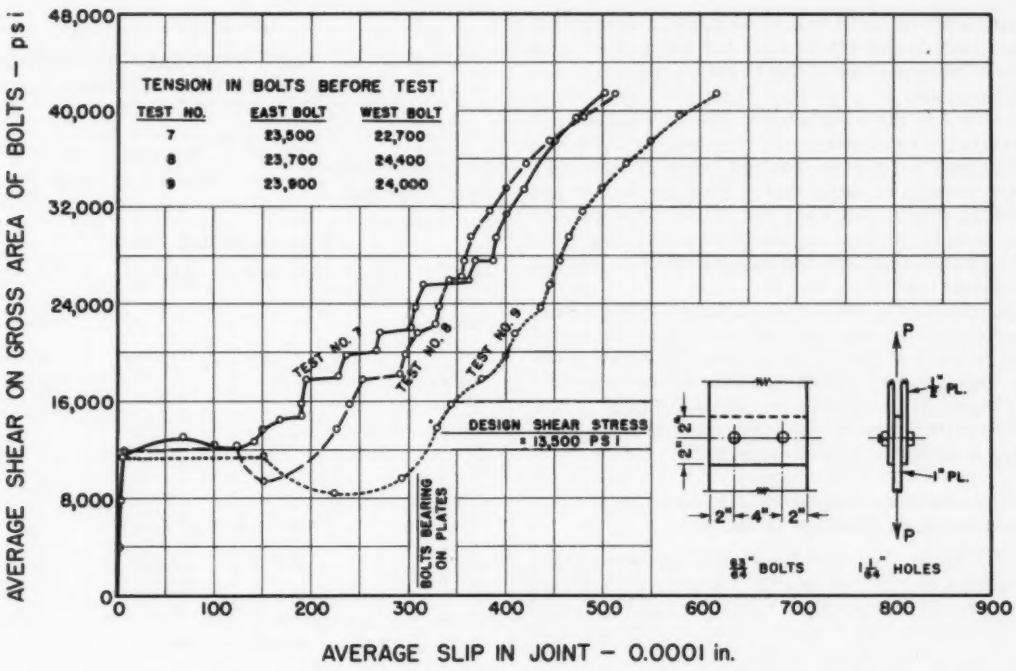

Fig. 6. Effect of Clearance of 1/32 In. in Bolt Holes upon Slip of Double-Lap Joints with Two 63/64-In.-Diameter Bolts in 1-1/64-In. Drilled Holes

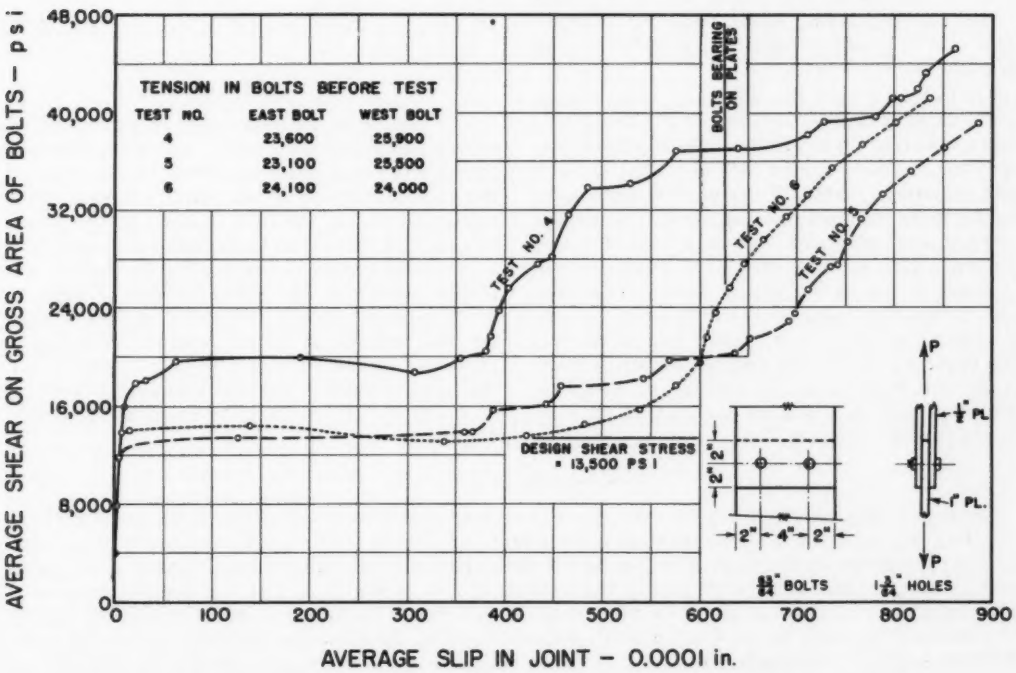

Fig. 7. Effect of Clearance of 1/16 In. in Bolt Holes upon Slip of Double-Lap Joints with Two 63/64-In.-Diameter Bolts in 1-3/64-In. Drilled Holes

clearance. More tests are necessary to determine whether this trend would hold for joints having a greater number of bolts. Such tests are part of the future program.

The effect of the clearance in the bolt holes upon the shearing stress necessary to bring the bolts into bearing upon the plates was not entirely apparent from the results of these tests. Test No. 9, like the previously discussed Test No. 22, did not subsequently sustain the load required to produce the first major slip until the bolts had slipped into full bearing on the plates.

An examination of the faying surfaces of the specimens after testing showed that a small area around the bolt holes was galled by the friction between the plates. The diameter of this galled area was approximately equal to the distance across the flats of the bolt. The mill scale on the remainder of the faying surfaces was only slightly disturbed.

Amount of Slip Necessary to Sustain Shearing Stress in the Bolts Equal to 13,500 psi

The shearing stress in high-strength steel bolts allowed by a number of design codes is 13,500 psi. The results of the tests of Type-A joints given in Table II indicate that only Tests No. 22 and 23 sustained a shearing stress of 13,500 psi in the bolts before the first major slip occurred. Similarly from the results of the Type-B tests reported in Table III, Tests No. 1, 2, 3, 4, and 6 sustained a shearing stress of 13,500 psi in the bolts before the first major slip. The remaining joints required a larger amount of slip to mobilize the friction necessary to sustain this design stress.

In Table IV are shown the values of the average slip in the joint which occurred before the joints sustained a shearing stress in the bolts of 13,500 psi. An inspection of these values indicates that most of the joints slipped at least half the amount necessary to bring the bolts into full bearing before the design shear stress was sustained. The only type of bolted joint tested which consistently underwent only a small amount of slip at the design shear stress was the Type-B two-bolt joint with a hole clearance of 1/64 in. and a bolt tension of 24,000 psi. Additional tests are required to confirm whether a small clearance in the bolt holes is more effective in reducing the amount of slip in a bolted connection than an increase in the bolt tension.

TABLE IV

AMOUNT OF SLIP NECESSARY TO SUSTAIN SHEARING STRESS IN BOLTS EQUAL TO 13,500 PSI

Test No.	No. Bolts in Joint	Clearance (in.)	Approx. Bolt Tension (lb.)	Am't of Slip for Shear of 13,500 psi
Type-A Bolted Joints				
16	1	0.063	18,000	0.0037
17				0.0588
18				0.0578
19	1	0.063	24,000	0.0033
20				0.0330
21				0.0084
22	1	0.063	30,000	0.0005
23				0.0010
24				0.0387
Type-B Bolted Joints				
1	2	0.016	24,000	0.0009
2				0.0005
3				0.0006
7	2	0.031	24,000	0.0147
8				0.0215
9				0.0328*
4	2	0.063	24,000	0.0006
5				0.0210
6				0.0013

*After coming into full bearing.

SUMMARY

The results of the initial part of a program of tests of bolted joints have been reported. The primary purpose of these tests has been the determination of the slip occurring in the joints under load. In one series of tests, the bolt tension in the joints was varied. The clearance in the bolt holes was increased in a second series of tests while the bolt tension remained constant. The small number of tests already made indicate that a reduction of the clearance in the bolt holes may be much more effective in decreasing the amount of slip in a bolted connection than an increase in the bolt tension. However, additional tests are necessary to establish this trend definitely.

"However, just as we ask from management a sympathetic understanding of the scientist's approach to his own work, so we must ask the scientist to make his own contribution to the simplification of managerial decision. The mission of the scientist is not only to add to natural and practical knowledge but also to interpret his results to his fellow men. For the second purpose the scientist has to be articulate in the right way. The scientist in industry must be able to expound the results of his work to the management, without clouding them in a framework of abtruse scientific phraseology. Although his work has taken shape in his own thoughts by way of a framework of scientific phraseology and imagery, it is the final result and its practical significance that are of real concern to management as a basis for executive action." E. V. Appleton, "The Scientist in Industry," *Research*, September, 1949.

HARDNESS AS A FACTOR IN ABRASION-RESISTANCE OF CONIFEROUS WOOD

Bror L. Grondal
Professor of Forest Products

B. L. Grondal

The modified Brinell hardness test originated by Janka[1] in 1906 and adopted with slight modifications by the U.S. Forest Service is useful in determining the gross hardness of woods of different species. This test, in which the load in pounds required to imbed a steel ball 0.444 inches in diameter into wood to a depth of 0.222 inches (or half of its diameter, with a projected surface area of one square centimeter) does not, however, indicate the effectiveness of the gross hardness of wood in resisting abrasion.

Early strength tests on wood included a hardness test which consisted in forcing a solid steel plunger, rectangular in section, upon the surface of the wood, the load required to produce an indentation of one-twentieth inch being recorded. On the basis of such a test, Roth[2] rates Douglas fir, southern and western hard pine, among other coniferous species, as "middling hard" woods, requiring over 1600 pounds per square inch (but less than 2,400 pounds) to produce an indentation of one-twentieth inch. Among "soft woods" requiring a lesser load to produce this indentation, Roth lists "the greater mass of coniferous wood: pine, spruce, fir, hemlock, cedar, cypress and redwood."

The test method described by Roth apparently gave such variable results that no hardness test was prescribed in the "Instructions to Engineers of Timber Tests" issued by the U.S. Forest Service as Circular No. 38 (revised) on March 31, 1909. However, under the heading "special tests" an abrasion test is described in this circular. A modified Dorry abrasion machine was to be used in which garnet paper was glued to the revolving disk. With the disk revolving at 68 r.p.m., the relative wear of a hard-maple block at 12 per cent moisture content 2 by 2 inches in cross section, and a corresponding block of the wood undergoing test was determined by measurement. Both blocks were forced against the garnet paper by clamps weighing 26 pounds each.

The Dorry abrasion test apparently proved unreliable, and publications issued by the U.S. Forest Service, including summaries of mechanical properties of woods prepared in 1917 by Newlin and Wilson[3] and in 1935 by Markwardt and Wilson[4], as well as the *Wood Handbook*[5] of the Service published in 1935 and revised in 1940, make no mention of the abrasion resistance of wood, other than the following brief statement by Markwardt and Wilson: "although hardness is the best available index of the ability of wood to resist wear, it is not so good a criterion of suitability as would be actual comparisons from some kind of abrasion tests that would more nearly simulate service conditions. However, no abrasion test for wood has yet been standardized and systematic results are not available."[4]

In short, the best that the U.S. Forest Service has to offer are hardness tests on nearly all of the woods that have been tested at the Forest Products Laboratory at Madison, Wisconsin. These include Janka tests on end, radial and tangential surfaces, and have been correlated with the specific gravity of oven-dry wood, based upon the volume of the wood at 12 per cent moisture content as well as the volume of green wood, indicating that all three hardness values (end, radial and tangential) vary approximately as the two and one-fourth power of the specific gravity. That such a relationship existed was realized by Janka[6] in his discussion of the specific-gravity-hardness relationships of Austrian spruce.

Busgen[7] during a period from 1904 to 1906 determined the hardness of 182 timbers by forcing a steel needle into the wood to a depth of 2 millimeters, noting the load in grams required, which, divided by 100, was recorded as a hardness number. Busgen's test was superseded by Janka's modified Brinell method, as being of more practical importance.

During recent years, Janka's test method has been subjected to criticism by numerous investigators. Pallay[8] in a series of tests on various woods found that the standard Brinell test was not adaptable to this purpose, and that Janka's method did not show as close a relationship between hardness and specific gravity as Krippel's method. Krippel forces a steel ball 25.466 millimeters in diameter into the wood to a depth of only 2.5 millimeters, measuring

the load applied. As the surface area of that portion of the ball that is pressed into the wood is therefore 2 square centimeters (the same surface area as in the Janka test, but with a much wider included angle) one half of the applied load is used as a numerical expression of hardness.

In the Brinell-Mörath method, the standard 10-millimeter Brinell ball is used, but it is forced into the wood under loads of 10, 50 or 100 kilograms when very soft, hard or very hard woods, respectively, are tested. The load is applied for 15 seconds, arrested for 30 seconds, and released in 15 seconds. A microscope is used to determine the area of the impression so that the square millimeters can be computed, the hardness being expressed in kilograms per square millimeter. Huber[9] concluded that this method was not well adapted for the testing of wood.

Huber extended his studies by investigating the effect upon hardness numbers by forcing the standard 11.284-millimeter Janka ball into the wood to various depths, ranging from 0.77 millimeter (or an included angle of 60 degrees) to 5.642 millimeter (the standard Janka test) and compared the results obtained with similar tests using a 30-millimeter ball. He found that the standard Janka test in only a few instances gave maximum hardness numbers, but a study of his tables and graphs fails to disclose convincing evidence that much would be gained by modifying Janka's procedure.

The hardness testing method described by Roth[1] was revived by Hoeffgen[10] who made a series of tests by impressing steel stamps, rectangular in section with slightly relieved sides to avoid frictional effects, into the wood. Stamps with face dimensions of 2.5 by 20 millimeters, 5 by 20 millimeters and 10 by 20 millimeters were used, and these were placed to span as great a number of annual growth rings as possible. While Hoeffgen obtained quite consistent results, shearing stresses quite obviously introduce another factor than "hardness," and his test methods are subject to the same disadvantages as those described by Roth.

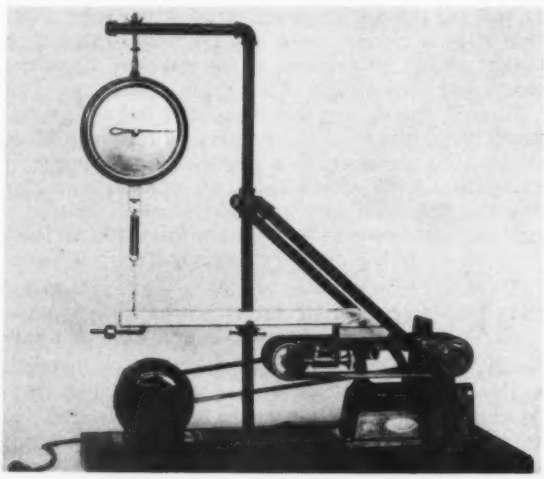

Fig. 1. Abrasion-Testing Device with Belt Sander

The chief complaint that has been directed against Janka's test is that the deep penetration of the ball into the wood introduces errors, as the wood is anisotropic, and that the hardness tests made in this manner cannot be related to the specific gravity and the strength of the wood with a high degree of precision. This complaint is not regarded by the writer as important. On the other hand, the resistance of wood to abrasion is decidedly important. The Janka test is desirable as an index of gross hardness, but resistance to abrasion involves other factors that gross hardness tests will not uncover.

Chaplin and Armstrong[11] at the Forest Products Laboratory at Princes Risborough, Bucks, England, constructed a rather elaborate device for testing the relative wear resistance of floors made of various woods. A fairly large metal-planer was equipped with two special tools, a "stamper or studded shoe to impart repeated impact blows, and a rubber or scuffer to rub off the fibers as they become loosened." A vacuum cleaner removed the dust and the 30-pound stamper, raised 7/16 inches by a cam and dropped 115 times per minute, and the scuffer, weighing 90 pounds and turning at 23 r.p.m., moved from side to side as the planer bed, carrying the floor sample, was fed to and fro for 50 hours. Quite significant results were obtained. It was noted that "the percentage losses in weight and in thickness in the other six hardwoods tested* appear to bear some relationship to the specific gravity values as shown by the curves. It is to be noted that the relationship is not rectilinear as is that of hardness to specific gravity. . ." The influence of hardness is further discussed, and the statement is made, in part, that "it will be appreciated that hardness can only serve as a broad indication of the wear-resistance, especially as it apparently has no relationship to surface breakdown."

In 1937, the writer constructed a rather simple sanding machine for abrasion tests on short lengths of flooring, which is illustrated in Figure 1. The wood sample, with a face 2-1/2 inches wide and 4 inches long, was attached to a pivoted aluminum shoe at one end of an aluminum beam supported at its middle by a universal joint. A balancing weight was provided at the other end of the beam. By means of a scale hooked to one end of the beam after balancing, with an interposed spring to compensate for vibration, a load of 5 pounds, or 1/2 pound per square inch, was applied to force the wood against the garnet paper on the sander. Table I shows some of the results that were obtained in an extended series of tests.

It will be noticed that the specific gravity-hardness relationship is very apparent, but that abrasion resistance (to sanding) and hardness is not closely

*Burma teak, because of its high natural oil content which affected the results, and Australian jarrah, containing large amounts of brittle resinous material, gave divergent results.

coordinated. The results were not of such significance that they were regarded by the writer as explaining, for example, why vertical grain western hemlock (*Tsuga heterophylla* (Raf) Sarg.) often exhibits wear resistance superior to that of Douglas fir (*Pseudotsuga taxifolia* (La Marck) Britton) when used as flooring.

Another type of abrasion test, which according to Chaplin and Armstrong[11] has been used by the Department of Forestry of New South Wales, employs a sandblast to abrade the wood. As described by Kollman[12] a superheated steam-air sandblast at a pressure of 30 pounds per square inch is controlled so that 2.9 kilograms of sand per minute is blown against the test specimen for two minutes. The specimen is partially covered by a circular washer to confine the effect of the blast to an area of 28 square centimeters. This machine undoubtedly indicates the resistance of wood to abrasion by sand, but complex factors are introduced which limit the usefulness of this type of test. Kollman also describes a grindstone test which is of slight interest.

TABLE I
TEST DATA OBTAINED WITH SANDING EQUIPMENT SHOWN IN FIGURE 1

Species	Grain	No. of Tests	Rings per Inch	Specific Gravity (oven-dry volume)	Average Hardness Janka test (lb.)	Loss in Sanding* (g)
Hemlock	V.G.	2	20	.41	504	1.53
	V.G.	4	23	.46	612	1.50
	V.G.	4	16	.50	663	1.66
	V.G.	2	28	.56	753	1.50
Douglas fir	V.G.	6	21	.44	519	2.01
	V.G.	8	28	.47	587	1.61
	V.G.	12	19	.51	691	1.42
	V.G.	4	16	.56	755	1.25

*One minute at 5 p.s.i., average of 3 runs per piece.

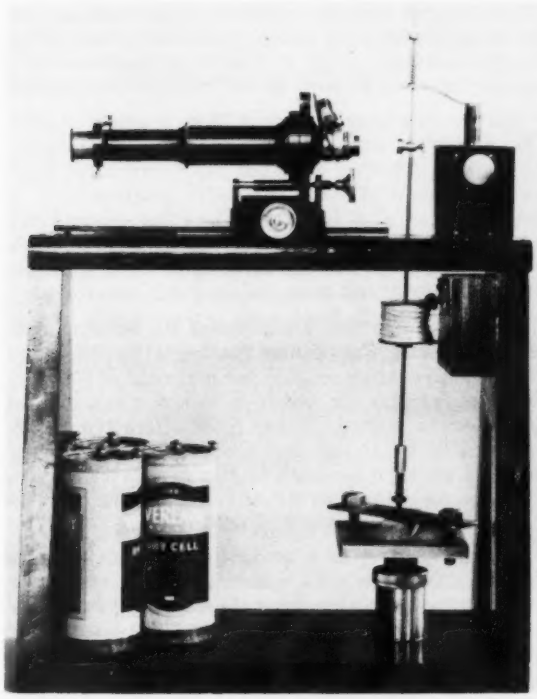

Fig. 2. Hardness-Testing Machine with Impact Loader

In 1937, Kollman[13] announced the development of a new abrasion-testing machine which had been constructed at the Prussian Forest Research Institute in Eberswalde. This rather elaborate machine stamps an artificial "iron shoe" soled with leather upon a 5 by 5 centimeter wood specimen 2-1/2 centimeters thick. A tightly stretched belt faced with coarse (No. 222) carborundum extends over the leather sole to furnish an abrasive surface. As the shoe stamps downward under a load approximating that of a man's foot, the specimen is automatically jerked lengthwise in a path that describes a sinusoidal curve. After 2500 stamps, the specimen is rotated so that the artificial shoe "walks across" the specimen, and after another 2500 stamps, "walks" at an angle of 45 degrees, and so on. The reduction in thickness of the specimen is recorded for each 2500 stamps. The machine appears to be well designed and compactly arranged, and seems to be the closest approach to a reliable abrasion test that has been developed. However, Chaplin and Armstrong obtained results with their machine that differ, materially, from test data presented by Kollman.

In 1920, in an attempt to explain the obvious disparity between the gross hardness and the wearing qualities, or surface hardness, of wood, a testing device was constructed under the writer's supervision by F. Roy Knapp, then a senior student in the College of Forestry at the University of Washington. The depth of the indentation produced by a 10-gram weight falling 10 centimeters to force a 2-millimeter sapphire ball (a Pathe phonograph needle) into the wood is measured by this device. In this manner, the hardness of the wood in any part of the annual ring (in a zone not much wider than 2 millimeters) can be given a numerical value. It was hoped that this testing device could be used in predicting the wearing qualities of wood subject to abrasion of any sort. Miyashita[14] used this test method in relating the "surface hardness" to the gross, or Janka-test

hardness, of 37 species of Japanese softwoods and hardwoods, with good results.

In 1931, the testing device just described was further improved and reconstructed (Fig. 2) under the writer's supervision by Welch,[15] who tested western red cedar (*Thuja plicata* D. Don), Douglas fir (*Pseudotsuga taxifolia* (La Marck) Britton), Sitka spruce (*Picea sitchensis* (Bong.) Carriere) and western hemlock (*Tsuga heterophylla* (Raf.) Sargent). Welch found that the spring wood in the hemlock was harder than that in the other species tested, but that the summerwood was not as hard as that of Douglas fir. "There is less variation, therefore, in the hardness (of the annual growth ring) of this species than in any other of the species tested." Welch computed "hardness numbers" in terms of grams per square millimeter. A testing machine using this impact loading has been employed by Chalais-Meudon, in France. A short description of this test and a summary of test results by Kollman[12] suggests that the Chalais-Meudon test was concerned only with the gross hardness of wood, and that no noteworthy contribution resulted.

In 1945, the writer designed a hardness-testing machine which applies a load at a controlled rate to cause a needle or point to penetrate the wood to a controlled depth. It consists of a pivoted steel beam with a holder for the penetrating point at one end. To the other end is attached a small dynamometer, improvised from a milk scale, which is in turn attached to a very small winch. When power is applied to the winch by means of a small electric motor (a drive obtained from an old dictaphone), any resistance to the downward thrust of the point into the wood is indicated by the dynamometer. Adjustable contact points on the beam and the supporting steel base of the machine make or break an 8-volt alternating electrical current. By means of a relay, the 120-volt current to the motor is cut off when the desired depth of penetration of the point has been attained.

Baker,[16] while working under an Engineering Experiment Station fellowship, investigated the relationship of specific gravity and the hardness of the springwood and summerwood in second-growth Douglas fir. Using the testing machine described in the preceding paragraph, Baker used an accurately ground "point" that presented a square end surface that had an area of 0.1 sq. millimeter. This was forced into the wood to a depth of 9.75 millimeter. The load required, in pounds and tenths, was noted as the hardness number. In this manner, 208 springwood and 210 summerwood samples, very carefully conditioned to a uniform moisture content, were tested. The specific gravity of the summerwood and springwood of the annual growth rings tested was determined by means of an adaptation of the Breuil mercury volumeter (Amsler & Co.), with a high degree of accuracy.

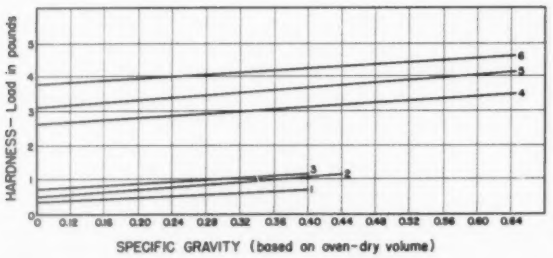

Fig. 3. Relationship Between Specific Gravity and Hardness of Douglas Fir Spring- and Summerwood

1, 2, 3. Springwood: end, tangential, radial surfaces
4, 5, 6. Summerwood: end, tangential, radial surfaces

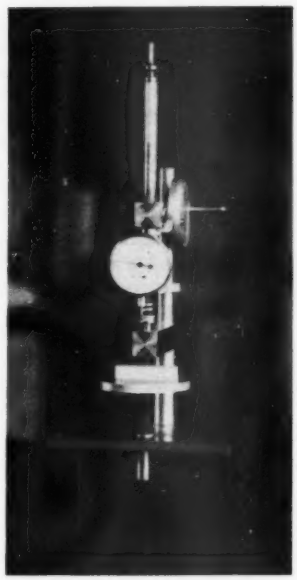

Fig. 4. Foster Manually Operated Hardness Tester

The chart shown in Fig. 3 shows the linear relationships between specific gravity and the hardness of springwood and summerwood, as determined by Baker. These suggest that the resistance to abrasion (as well as the higher strength values) exhibited by dense Douglas fir is influenced by a greater average density of the springwood, as well as that of the summerwood.

During the spring quarter of 1949, a senior student, Guy J. Foster, working under the writer's direction, on his own initiative designed and constructed a new manually operated hardness-testing machine (Fig. 4). Depth of penetration is indicated by a dial-micrometer, and the compression of a spring bearing upon the penetrating point is read directly from a graduated circle on the crank disk.

Using this machine, Hung-Yeuan Tu, working under an Engineering Experiment Station fellowship, made tests on the springwood and summerwood of 87 specimens of Douglas fir, western hemlock and longleaf pine flooring strips. These tests differ from those made by Welch in that they indicate that the springwood of western hemlock is slightly softer than the springwood of Douglas fir, but that the summerwood in hemlock is considerably softer.

Certain factors, such as the resilience of the wood and inclusion in the cells, undoubtedly have a considerable bearing upon abrasion resistance. Uniformity of hardness of spring- and summerwood will provide material that will resist abrasion to a degree dependent upon the specific gravity of the wood. Further tests are needed, however, before definite ratings of the comparative abrasion resistance of woods can be made.

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Notes and Comments

ENGINEERS IN THE NEWS

A revised edition of *Fundamentals of Vacuum Tubes* by **A. V. EASTMAN**, Professor and Executive Officer of Electrical Engineering, has just been issued by McGraw-Hill Book Company.

F. A. McMILLIN, whose thesis on electrolytic chromium appears in abbreviated form in this issue, is now a research engineer with the California Research Corporation at Richmond, California.

At the national meeting of the Society of American Foresters held in Seattle, October 10-15. **H. D. ERICKSON**, Associate Professor of Forest Products, presented a paper on "Progress in the Manufacture of Pulp, Chemical, and Board Products from Mill and Logging Waste."

O. H. SCHRADER, JR. appeared at the same meeting with "New Developments in the Forest Products Industries." Dr. Schrader, Technical Director of the Washington State Institute of Forest Products, also attended a wood utilization conference at Harvard University. Dr. Schrader has been appointed manager-director of the Douglas Plywood Association in Tacoma and will leave for his new job at the end of the fall quarter.

NEW RESEARCH PROJECTS

Project 72. The Use of Ozone in Treatment of Sewage. R. G. Tyler, Professor of Sanitary Engineering, Supervisor; Willard Mathews, Research Fellow.

Project 73. A Lightweight Aggregate Survey. P. D. Johnson, Assistant Professor of Mineral Engineering, Supervisor; Mervyn Shnider, Research Fellow.

Project 74. The Disposal of Industrial Wastes. R. G. Tyler, Professor of Sanitary Engineering, Supervisor; M. J. Westin and R. E. Dunn, Research Fellows.

Project 76. Bolts as Structural Connectors. R. A. Hechtman, Associate Professor of Structural Research Supervisor: D. R. Young, Research Fellow.

Project 77. Strain Distribution as Affected by Temperature in the Vicinity of the Transition Temperature. R. A. Hechtman, Associate Professor of Structural Research, Supervisor; D. R. Young, Research Fellow.

Project 78. Design of Microwave Frequency Standards. A. E. Harrison, Associate Professor of Electrical Engineering, Supervisor.

A BASIC AMPLIFIER FOR ELECTRONIC INSTRUMENTATION

Andrew B. Jacobsen

Research Associate in the Engineering Experiment Station

A. B. Jacobsen

Introduction

Over a period of years the writer has given advice, circuit diagrams, and consultation to many who need electronic instrumentation for research but are not directing their attention to design and construction. Even with considerable follow-up these people spend hours on assembly and wiring, and days adjusting and testing their equipment before they can use the instruments to do the job at hand.

Because the development of electronic instruments for research requires for each system a more or less fresh start involving a large amount of construction and test work before the new circuits can be used, a new approach is needed which will reduce the time and monetary cost expended.

Description

The basic amplifier (Fig. 1) described in the following pages was the outgrowth of several years work in the Engineering Experiment Station under Project No. 28, "Electronic Measurement and Control," under the supervision of the writer assisted by LeRoy D. Barter, Research Assistant in the Engineering Experiment Station. It has been devised to provide the main circuit elements that are required in the majority of electronic instruments. These circuits, as building blocks, will reduce the effort, cut the time required, and minimize the cost of electronic instrumentation. For example, the basic amplifier may be used to provide the amplification and power required to utilize a recording meter of low sensitivity. (See Fig. 2.) It may also be used as a vacuum-tube voltmeter or as an amplifier for oscillographic work.

The block diagram, Fig. 3, shows the over-all elements of this basic amplifier unit: a power supply and regulator, a main amplifier for alternating and direct current, a plug-in pre-amplifier for additional a-c amplification, a calibrated attenuator, input switching, and a meter circuit.

The unit provides the functions of an a-c and d-c vacuum-tube voltmeter of the amplifier type and will be of considerable value without additions or modifications because of the ranges available: d-c, from 0-0.5 v to 0-1000 v; a-c, from 0-1 mv to 0-1,000 v.

Panel and chassis space, including spare sockets, is provided for additional amplifiers, detectors, modulators, oscillators, bridge circuits, filters, regulators, and computing elements as required. Power outputs for external circuits are provided.

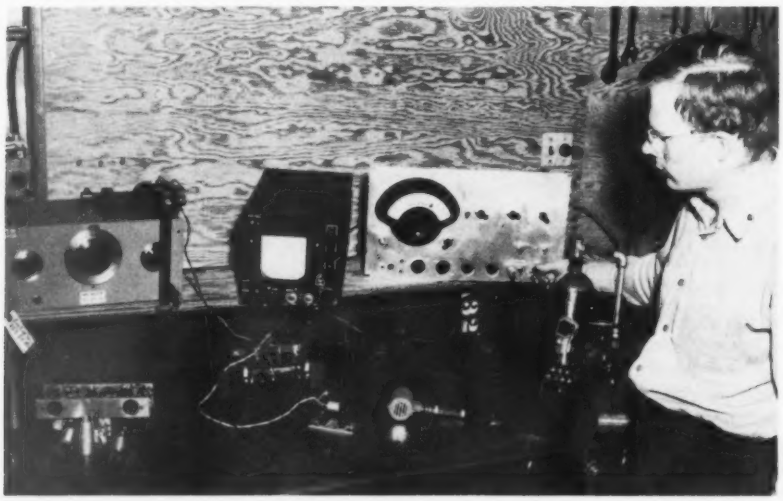

Fig. 1. L. Barter with Demonstration Set-up of Basic Amplifier

Much of the waste involved in the usual specially assembled electronic instrument development can be eliminated by using this unit as the heart of the system.

Uses

The basic amplifier performs the functions of an a-c and d-c vacuum-tube voltmeter and is sensitive enough to be used in electrochemical measurements such as those of a pH meter.

With the addition of a crystal rectifier probe the frequency range may be greatly extended.

Enough gain is available to operate directly with many strain gauges, pressure gauges, and vibration pickups.

More than one basic amplifier

or the use of several of the plug-in pre-amplifier units may aid in setting up the more complicated carrier-signal type of instrument.

For the measurement of small d-c potentials a bridge modulator plug-in unit has been devised and may be used to convert from small d-c potential differences to alternating current for amplification and phase detection by a plug-in clamping detector.

In measurements where varying resistance, inductance, or capacitance is available, either 60 cycles may be used as the carrier frequency or a plug-in oscillator unit may provide a higher frequency carrier. Fig. 4 shows several types of plug-in units.

At present four of these units are available for use at the University of Washington, one preliminary model which has been in use for several months, and three new units of more finished construction. Nine of the plug-in pre-amplifiers are available in addition to one in each of the four basic amplifier units.

Utilization of these units can be much higher than the usual specialized units. For example, one basic amplifier with auxiliary plug-ins or other attachments might be used for static and dynamic strain-gauge amplification and indication, or as an amplifier and indicator with a microformer accelerometer, or for vibration analysis with a microphone or phono pickup, or as a null indicator for bridge measurements, as well as in other applications where amplification and indication are required.

Extending the range and usefulness of other laboratory instruments is an important contribution of this unit. The main amplifier may be used to provide direct coupled amplification and deflection for an ordinary cathode-ray oscilloscope. Recording instruments may be utilized more fully with the amplifiers in this unit.

The regulated plate supply may be used in conjunction with an additional unregulated supply to provide a much higher voltage regulated supply. The 250-volt supply is regulated well enough to provide a secondary standard of potential for many applications.

Amplifier Circuits

The direct-coupled main amplifier has an input cathode follower and push-pull output with a direct-coupled feedback circuit. There are so many uses for a direct-coupled amplifier with push-pull output that the extra circuit complications seem justified. Balancing of this amplifier is accomplished by a zero adjust potentiometer which introduces a d-c potential to restore circuit unbalance, to offset residual d-c potential of input signals, and to set zero of certain indicators (cathode-ray tubes, recording galvanometers, etc.)

Fig. 5-a, a simplified schematic of the main amplifier, shows that the amplifier may be thought of as a four-terminal network in which the input is very nearly the difference of the input potentials and the output is the difference between the output plates.[1] When single-ended output is desired, either a transformer may be connected from plate to plate with a series condenser, or direct coupling may be obtained by shorting one plate directly to + 250 v and taking the output from the other plate.

The useful frequency range of this amplifier with feedback circuit R_a, R_b, is from zero to 150 kc (down 3db at 200 kc) when used at a gain of 20 to 30 depending on the lowest voltage scale desired. With the feedback circuit disconnected, the gain is about 680, and the output impedance is approximately 15,000 ohms. Ordinarily the gain is reduced to 20 by selecting the value of R_a and the output impedance is then approximately 500 ohms. The feedback circuit, in other words, is used to stabilize the gain, lower the output impedance, and reduce the amplitude and phase distortion.

A direct current amplifier may be checked for intermodulation distortion very easily by applying a small a-c input and a variable d-c input and noting the variation in a-c gain with d-c output. Such a test

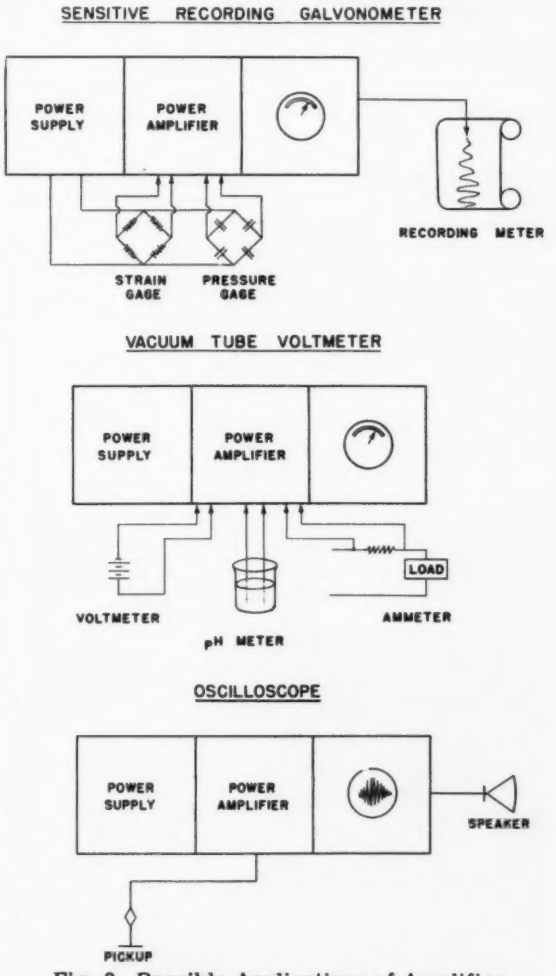

Fig. 2. Possible Applications of Amplifier

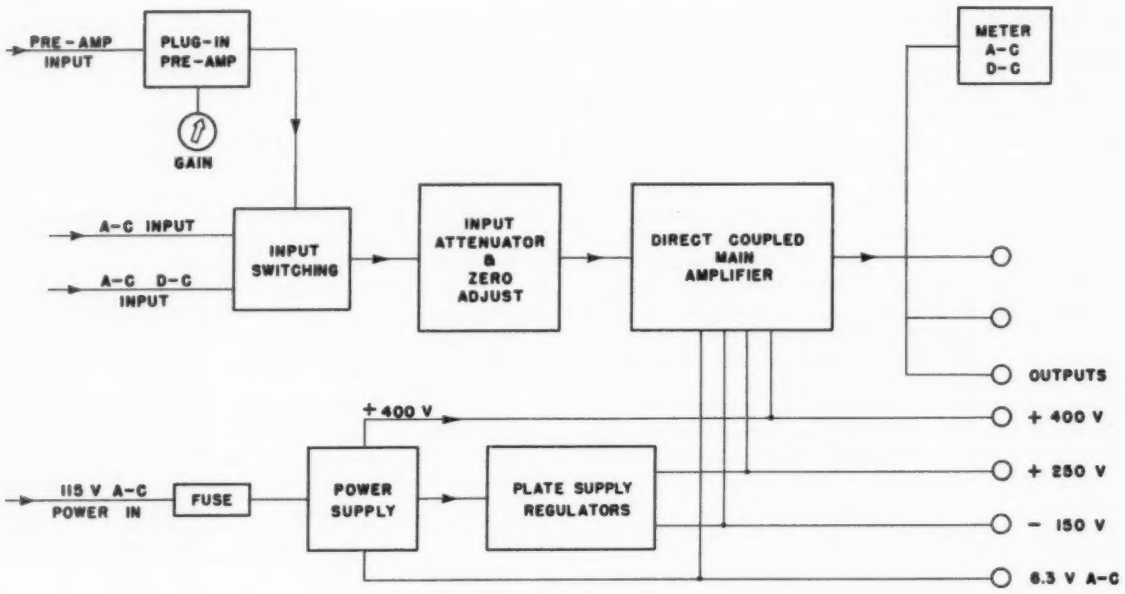

Fig. 3. Block Diagram

on this unit is plotted in Fig. 6. For ± 75-v output, the intermodulation distortion is less than ± 2 per cent.

The plug-in pre-amplifier[2] gain is normally ten (Fig. 5-b) set by an internal feedback circuit; however, the circuit is available at the socket and by means of the gain-control potentiometer and switch, the gain may be changed from 10 to 30 and adjustable to 500.

The input attenuator is made up of composition resistors selected to an accuracy of 1 per cent. Steps were chosen for scales in the ratios of 5, 10, 20, 50, 100, 200, 500, and 1000.

The resistance-capacitance circuit associated with the input switching removes the d-c component when measuring alternating current. The input without the attenuator is available when required.

The metering circuit uses a long scale 0-1 ma meter with a 100-k multiplier resistance for 0-100-v direct current. An oxide bridge rectifier and series resistor provide a scale of 0-100-v rms for alternating current. A meter requiring a minimum of current is desirable so that it may be used even when other loads are connected. A factor of 5 higher sensitivity is available by actuating the push-button switch which shunts the multiplier resistors.

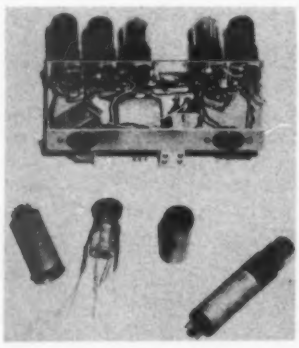

Fig. 4. Types of Plug-in Units

A plug-in 2-in. cathode-ray tube indicator has been developed which utilizes the power supply available and is useful in many applications.

Power Supply

The power supply (Fig. 3) is a conventional full-wave rectifier and section filter for 400 v, and a half-wave rectifier and resistance-capacitance filter for -150 v. A VR150 is used to stabilize the -150-v supply. An accurate voltage reference is obtained by the use of an RCA 5651 glow tube at a nominal +87 v with a claimed stability of ± 0.1 v.

A conventional type of voltage regulator[3] is used to obtain the +250-v supply. Ripple is less than 6 mv and the output impedance is less than 4 ohms. A heater supply with a hum-balance potentiometer is available at 6.3 v.

Conclusions

The basic amplifier unit plan will reduce costs and save time in applying electronic instrumentation to research problems. By constructing a number of these units as a group the cost per unit may be greatly reduced. In small quantities, 5 to 15 units, the cost of labor and materials will be about $100 for each unit, not including overhead. One of the most important savings in group construction is in the test and calibration labor required for each unit.

These standardized units will greatly facilitate the assembly of special electronic instruments as well as supplement and extend the usefulness of other laboratory instruments. Moreover, their use will minimize time lost because of defective units.

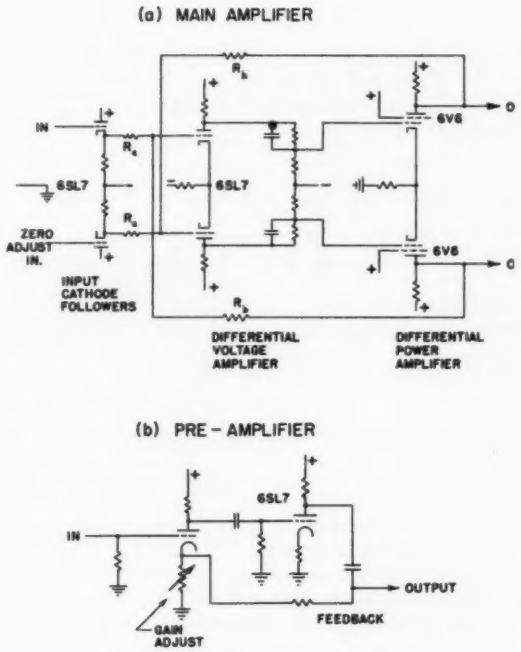

Fig. 5. Simplified Schematic Diagram

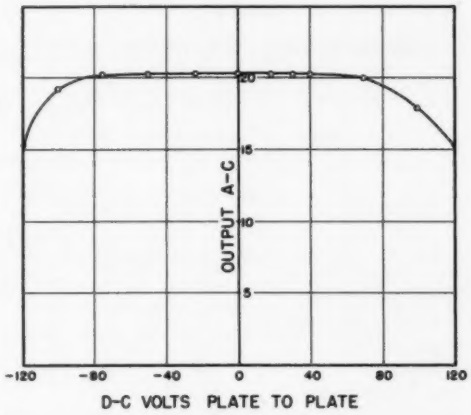

Fig. 6. Intermodulation Distortion

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Local Shale and Clay Deposits Show Promise for Lightweight Aggregates

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Assistant Director of the Experiment Station

The rapidly expanding public acceptance of pumice blocks for construction in the Pacific Northwest, tempered by some of the shortcomings of the blocks, has resulted in widespread curiosity about other potential lightweight aggregates. Commercial practice in other parts of the United States has suggested the examination of bloatable clays and shales as possible sources of material in the Seattle area.

A strange circumstance in this region has been the high price differential commanded by pumice blocks over sand and gravel blocks. Whereas in the Middle West the price differential for a lightweight aggregate block is normally one cent, and seldom exceeds two cents, in the Seattle area, the pumice block, the only lightweight aggregate used in appreciable volume, frequently retails for 50 per cent more than the sand and gravel block. The cause of this difference apparently lies, first, in the demand for the light weight of the pumice block combined with its insulating properties and its pleasing texture and color, and, second, in the fact that the pumice deposits being used at present are located some distance from Seattle, making transportation cost the principal item. The middle west lightweight aggregate block is made either from expanded clay and shale, or from blast furnace slag.

The extensive clay and shale deposits occurring near Seattle, suggest, from experience in the Portland area, that lightweight aggregates from blown clays and shales might well compete with pumice on a price basis in the Seattle marketing area.

A comparison of the properties of several samples of commercially available pumice and blown clays and shales reported by Price and Cordon[1] and by Cluge, Sparks, and Tuma[2] in recent issues of the *Journal of the American Concrete Institute*, indicates that the blown aggregate from these materials fits part way between pumice and sand-and-gravel. From data reported there, the summary in Table I was compiled,* and the following conclusions might be drawn.

*On the basis of each sample having the same number of sacks of cement per cubic yard.

TABLE I

COMPARISON OF PROPERTIES OF CONCRETES WITH THE SAME CEMENT AGGREGATE RATIO

7±.1 sacks of cement / cu yd

Property	Bloated Shale*	Pumice*	Sand** and Gravel
Thermal Conductivity	56	100	28
Compressive Strength	50	33	100
Compressive Strength-to-Weight Ratio	100	50	76
Absorption	50	25	100
Thermal Expansion	63	63	100
Shrinkage	63	63	100

*Samples commercially available in the western states. Size distribution reported in Reference (1); work done by U.S.Bureau of Reclamation, Denver.

**From the Potomac River. Size distribution reported in Reference (2); work done at Washington, D.C.

drawn.

1. Strength of lightweight concrete depends upon strength of the aggregate and sacks per cubic yard of cement. However, for each density of lightweight concrete there appears to be an optimum sacks per cubic yard beyond which additional cement does not improve strength. For example, with a density of 50 lb per cu ft, 1000 psi compressive strength was the best obtainable regardless of cement content; at 80 lb, 2000 psi, and at 100 lb, 3000 psi. On the other hand, the stronger the aggregate, the stronger the concrete, with no practical limitation.
2. The strength of three of the pumice samples tested (aggregate, not concrete) varied from one third to one half that of the expanded shale samples.
3. For concrete with compressive strengths in the normal construction range, the type made from bloated shale requires substantially less cement than that made with pumice for the same compressive strength, although the latter type has a better *k* factor. See Table II.
4. Thermal conductivity varies with density.

This work, coupled with other unpublished data from the Portland area, indicates a technological need in Seattle for blown shale aggregate. The freight rates to the Seattle area from an existing plant near Portland seem to rule out that source. The plant located at Woodinville, Washington has not produced aggregate in volume. These considerations led the Engineering Experiment Station to do exploratory work on a number of clay and shale deposits located in the Seattle area, to determine if any of them showed good bloating properties.

TABLE II

COMPARISON OF PROPERTIES OF CONCRETES WITH THE SAME COMPRESSIVE STRENGTHS

Type of Aggreg.	Compressive Strength					
	1000 psi			3000 psi		
	Sacks /cu yd	Unit Wt # /cu ft	*k*	Sacks /cu yd	Unit Wt # /cu ft	*k*
Bloated Shale	3.0	83	3.3	5.0	88	3.5
Pumice	4.0	72	2.1	7.5	86	2.5
Sand and Gravel	2.0	114	6.0	3.8	136	6.2

During the past summer, under Engineering Experiment Station Project No. 73, the Department of Mineral Engineering gathered more than eighty samples of clays and shales from deposits located adjacent to the Seattle, Tacoma, and Everett marketing area. A quick screening test was used to eliminate the samples which showed no indication of bloating when heated to temperatures of 1100, 1200 or 1260° C.

Bloating tendencies were shown in twenty-four of the eighty samples tested in a stationary kiln at the three firing temperatures. Samples of these shales and clays were then fired in a rotary kiln and ten of the twenty-four bloated sufficiently to indicate possible commercial sources of raw material for lightweight aggregate manufacture.

The work done by the University has been entirely exploratory. No research into causes of bloating or in the development of processing technique for individual samples was attempted. No additives were used; only raw clay and shale were fired.

Future work contemplated includes more thorough sampling and testing of clays and shales from the deposits from which bloatable materials have been found, in the hope of locating a commercially attractive deposit and thus answering one of the primary questions of any individual or company interested in producing blown aggregate in the Seattle area.

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"Scientists have their ambitions and they respond to stimulus and incentive. . . . For stimulus they require contact with their scientific colleagues, scientific talk . . . and so on. As for incentive, there is the enthusiasm and the challenge of the scientific chase."– E. V. Appleton, "The Scientist in Industry," *Research*, September, 1949.

ELECTROLYTIC CHROMIUM FROM FUSED SALT BATHS*

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Introduction

Olivine deposits in the State of Washington have been found to contain a low percentage of easily separated[1] chromite, $FeO.Cr_2O_3$. As the deposits may someday become an important source of magnesium, an investigation of metallic chromium production from the potential by-product, chromite, seemed justified.

A preliminary literature survey revealed that both the U. S. Bureau of Mines[2,3] and the Pittsburgh Plate Glass Company[4] had attacked the problem by chlorination of the ore, and that after fractional condensation the former workers had produced metallic chromium of high purity by continuous reduction with hydrogen.[5] The Electrometallurgical Section of the Bureau of Mines had evolved a process whereby the ore was fed into the anolyte of a sulfuric acid cell and quite pure chromium was produced.[6,7]

Considering the abundance of electric power available in the Northwest and the suitability of powdered metallurgy for metals with high melting points such as chromium's 1615°C, an investigation of the electrolytic production of powdered chromium seemed expedient.[8] Two factors influenced the choice of a type of bath to be used. First, the powdered metal has been obtained from aqueous solutions.[1] Second, the electrolysis of fused salts has long been recognized as an effective means of preparing metals, Sir Humphry Davy's work first reported in 1801 having led to the isolation of sodium and potassium. Therefore a fused medium was selected. Any one of three types of deposits was hoped for: (1) a hard, brittle deposit that could be crushed to powder; or (2) a soft, spongy deposit that could be rubbed into a powder; or (3) direct deposition of finely divided particles.

While the standard electromotive series is not applicable to fused systems, Yntema's work showed iron to be more noble than chromium in fused sodium and aluminum chlorides.[9] Thus it seemed wise to supply the chromium as the sesquioxide or as a technically pure salt, rather than as chromite.

With the foregoing facts in mind, the investigation into the production of powdered chromium from fused baths by electrolysis was undertaken.

Literature Summary

While reports on work relevant to the problem were by no means abundant, the merits of several baths could be established. Three basic types of fused systems have been considered, namely: (A) mixtures of oxides; (B) those using chlorides as solvents; and (C) fluoride baths. The results of previous workers as well as some fifty of our own preliminary experiments soon disclosed the fact that the fluoride baths were capable of producing oxide-free metal.

Apparatus and Experimental Method

Essentially the majority of the experiments were performed with graphite crucibles machined from pure graphite electrode stock, the crucibles being the anode and heated in controlled temperature fur-

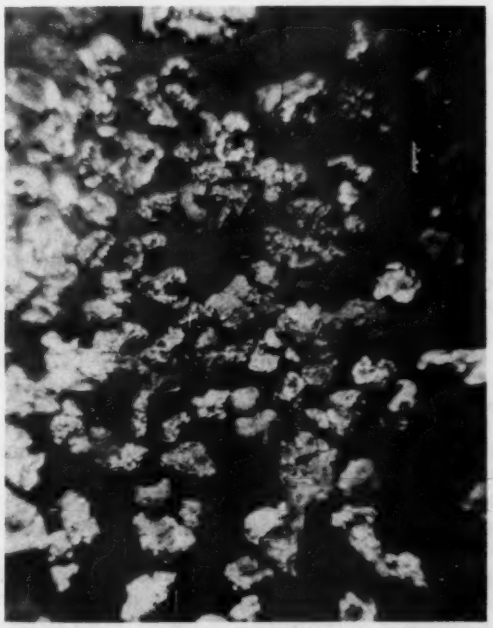

Fig. 1. Photomicrograph of Chromium-Boron Alloy
(x 40)

*Abstracted by G. L. Putnam, Research Associate in Chemical Engineering, from the thesis submitted by F. A. McMillin for the degree of Master of Science in Chemical Engineering.

TABLE I

QUANTITATIVE RUNS WITH FLUOBORATE BATH

Run No.	Current Density $\frac{amp.}{dm^2}$	Ave. Temp. C.	Ave. Voltage (V.)	Amp.-Hrs.	Wt. of Metallic Product (mg.)
13	35	805	5.2	8.0	263
14	35	850	4.9	7.2	10
15	35	790	5.1	16	425
16	40	765	7.6	33	2,190
17	55	765	4.6	53	3,516

naces. The cathodes used included stainless steel and graphite. Since the time required per experiment was four hours or more, several trials were made simultaneously using varying current density and electrolyte compositions.

Results

The best results obtained are given in Table I.

Standard Procedure

(1) All baths were 44 per cent NaF, 40.5 per cent KHF_2, 9.5 per cent B_2O_3, and 6 per cent Cr_2O_3.

(2) All runs were in electric furnace with graphite anode and crucible-cathode.

(3) An atmosphere of carbon dioxide was maintained over Runs 16 and 17.

(4) Current efficiency for chromium reduction was 8.55 per cent for Run 16, and 8.45 per cent for Run 17.

The product of the fluoborate system was an silver-colored alloy of chromium and boron having 8.2 parts by weight of chromium per part of boron. A photomicrograph of the powder is given in Figure 1.

Since the fused bath consists entirely of water-soluble salts which can be purified by recrystallization, it is believed that further work on the method may be justified. Before the method would approach commercial success, however, it would be necessary to obtain higher current efficiencies, and, moreover, it apparently will be necessary to develop the method so that a boron-free product is obtained.

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Microwave Frequency Standards Offer New Research Interest

Dr. A. E. Harrison, Associate Professor of Electrical Engineering, recently in Washington, D. C., to confer with United States Bureau of Standards, also visited the Office of Naval Research which has been interested in the study of microwave frequency standards. Engineering Experiment Station Project No. 78, which deals with this subject, was recently set up under the supervision of Dr. Harrison.

The present emphasis in the development of frequency standards in the microwave region (1000 to 6000 megacycles per second) is on primary standards utilizing molecular resonances, with little attention paid to the design of good secondary standards. Microwave applications in the state of Washington include relay systems for the Bonneville Power Administration, dielectric heating devices, and possible applications in the plywood industry.

A microwave frequency standard at the University for calibrating wavemeters and similar devices for use in the field, will serve these interests and be a logical extension of the present frequency standard.

The project proposes to design a frequency standard utilizing phase modulation of klystron frequency multipliers. The possibility of making such a device non-resonant so that standard frequencies over a wide band are simultaneously available, is also to be investigated.

Dr. Harrison's interest in multiwave frequency standards started during his association with the Sperry Gyroscope Company in klystron frequency-multiplier tubes, and the project now under way continues his work in this field.

During the past summer, Dr. Harrison was a research associate in the microwave laboratory at Stanford University where he was engaged in tests on a high power klystron amplifier being developed as a part of the linear acceleration program of the physics department at Stanford.

Distinction Marks Chemistry Department

The tradition of research activity established and maintained in the Department of Chemistry and Chemical Engineering by Dr. Henry Kreitzer Benson, Professor of Chemical Engineering for forty years and department head for twenty-eight, is being ably continued under the leadership of Dr. Paul C. Cross, recently appointed Executive Officer. Pictures of both men appear in the front illustration of this issue.

At the beginning of the Fall Quarter, 1949, of the Department's approximately 150 graduate students, 52 were in Chemical Engineering. At present eight of these men hold Engineering Experiment Station fellowships.

HENRY KREITZER BENSON, who came to the University of Washington in 1904 as a young assistant professor, was destined to take an active part not only in the academic growth of the Chemistry Department of the University, but also in its contribution to the industrial development of the state. To add to his degrees of A.B. and A.M. from Franklin and Marshall College, he shortly afterward took leave to complete work for his doctorate at Columbia, and returned to Washington in 1907 as Professor of Industrial Chemistry. In 1920 he became head of the department, a post which he continued to hold until 1947, when he was compelled by university age regulations to retire from active teaching and administrative duties.

Throughout his university career, and continuing up to the present time, Dr. Benson's interests have been varied and significant. He was with the U.S. Bureau of Soils and State Geological Survey for three summers, and in 1914 was commercial agent for the U.S. Bureau of Foreign and Domestic Commerce, studying lumber by-products. During World War I he was State Director of the U.S. Naval Advisory Board and served as captain in the Research Section of the Nitrogen Division of Army Ordnance. He was chairman of the Division of Chemistry and Chemical Technology of the National Research Council (1931-32) and delegate to the International Conference of Chemistry held at Rome, Italy, in 1938.

Dr. Benson was a charter member and the first chairman of the Puget Sound Section of the American Chemistry Society organized in 1909. In 1928 he organized a conference of technical men at the University, which resulted in the formation of the Pacific Section of T.A.P.P.I. At the last meeting of the National Association, held in Portland, Dr. Benson gave the address of welcome and described the early activities of the Section. He is now regional chairman of the committee of Chemical Products of T.A.P.P.I.

He was also the first chairman of the Washington-Oregon Chapter of the A.I.Ch.E. organized in 1945. He has been chairman of the Washington State Chem-

PAUL CLIFFORD CROSS, who comes to the University of Washington as Executive Officer of the Department of Chemistry and Chemical Engineering from Brown University where he held a similar position, already has had a career of teaching and research in eastern, western, and northern universities.

Upon leaving Geneva University in 1928 with a B.S. degree, he did graduate work at the University of Wisconsin where he received his M.S. in 1930 and Ph. D. in 1932. The following three years were spent in research at the University of Wisconsin and California Institute of Technology, under research grants. From 1935 to 1936 he was Research Associate at Stanford University under a grant from the Carnegie Institution, and for the two years following held an assistant professorship at Stanford. Brown University called him as associate professor in 1938 and promoted him to full professorship in 1942 and to chairman of the Department of Chemistry in 1942.

During the war, Dr. Cross served in various capacities in connection with war research projects at Brown University under contracts with the U.S. Naval Research Laboratory, National Defense Research Committee, and U.S. Army Engineers. The first year of his leave of absence 1943-1945 he was Deputy Research Director, Underwater Explosives Research Laboratory, at the Woods Hole Oceanographic Institution, and the second year Research Director.

During the summer of 1946 Dr. Cross was a lecturer at Harvard University, and for the following three years directed the Metcalf Research Laboratory at Brown University.

Many of Dr. Cross' thirty-one publications to date deal with molecular structures. Some of his most outstanding publications are the following, arranged in chronological order.

Molecular Vibrations of Three Particle Systems with Special Applications to the Ethyl Halides and Ethyl Alcohol (with J. H. Van Vleck), J. Chem. Phys., 1, 350-356 (1933)

HENRY KREITZER BENSON

(continued from p.31)

urgic Committee since 1942. Other affiliations include Sigma Xi, Phi Lambda Upsilon, Tau Kappa Epsilon, Forest Products Research Society, and A.A.A.S.

His publications, over 100 in number, include a textbook, Industrial Chemistry for Engineering Students (Macmillan, 1914) and many contributions to scientific journals. In the field of pulp and paper technology, the following are of especial interest.

"Rate and Extent of Anerobic Decomposition of Sulfite Waste Liquor by Bacteria of Sea and Fresh-Water Muds," written as a doctorate thesis by A. M. Partansky under Dr. Benson's direction, Proceed. Nat. Acad. Sc., Vol. 20, No. 10 (Oct., 1934), pp. 542-551, and Vol. 22, No. 3 (March, 1936), pp. 153-158

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When freed from active academic duties in 1947, Dr. Benson became Director of Research at Laucks Laboratories, Inc., where his extensive experience in lignin research continues to serve Washington industry.

PAUL CLIFFORD CROSS

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Also in preparation is a book entitled "The Theory of Infra-red and Raman Spectra," with E. Bright Wilson, Jr. and J. C. Decius as co-authors.

Dr. Cross' present research in molecular geometry, which has as its ultimate purpose an understanding of molecular interactions, was started at Brown University. To enable him to equip a laboratory to continue this work at the University of Washington, the Research Corporation, with headquarters in New York, recently made available a grant to the University of $18,000.

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